

25,433 / C

1894

12

d-~~11~~ 11

Mathematical Elements
OF
NATURAL PHILOSOPHY,
CONFIRM'D BY
EXPERIMENTS:
Or, an INTRODUCTION to
Sir *ISAAC NEWTON*'s Philosophy.

Written in *Latin* by the late
W. JAMES s'GRAVESANDE, LL. D.
Professior of Mathematicks at *Leyden*, and F. R. S.

Translated into *English* by the late
J. T. DESAGULIERS, LL. D. F. R. S.

And Published by his Son:
J. T. DESAGULIERS.

The SIXTH EDITION greatly improved by the AUTHOR,
and illustrated with 127 Copper Plates all new engraven.

VOL II.

LONDON:

Printed for W. INNYS, T. LONGMAN and T. SHEWELL, C. HITCH, in
Pater-Noster-Row; and M. SENEX, in *Fleet-Street*.

M.DCCXLVII.



Mathematical Elements

OF

NATURAL PHILOSOPHY

CONFIRM'D BY

EXPERIMENTS.

BOOK IV.

PART I. Of Air, and other elastic Fluids.

CHAP. I.

That Air has the Properties of Fluids.

THE Fluids, that we consider'd in the third Book, have contiguous Parts, which cohere but a little, between which nevertheless some small Cohesion is observ'd. These Fluids are not brought into a less Space by Compression; at least, if there be a Diminution of Space, it is so small, that it could not be discover'd hitherto, in any great Compression whatever; for that which seems to shew such a Diminution in some Experiments, may be easily attributed to another Cause. Those Fluids have this Property also, they are contain'd in Vessels open at top. 2074.

But there are other Fluids, which are to be restrain'd on all Sides lest they shou'd flow away; and occupy a greater, or less Space, according as they are compress'd by a greater, or less Force: These are call'd elastic Fluids; and among these the Air, with which the Earth is surrounded, is the chief. I shall speak of this now, and demonstrate first of all, that this is to be rank'd amongst Fluids. 2075.

We have often spoken of the Air already, and as we live in, and are always encompassed by it, we must have Regard to it's Effects in several Experiments, as we have said; but now we shall consider it's Properties singly.

2076. We call that Fluid, which covers the Surface of the Earth, and surrounds the Earth on every Side, the Air.

2077. But it is manifest that the Earth is surrounded by a Fluid; for we observ'd that it is cover'd by a Body, that gravitates, whose Parts yield to any Impression, and are easily mov'd among themselves, which presses according to it's Height, and whose Pressure is equal every Way.

2078. Many call any elastic Fluid whatever Air; others affirm that in the Air, which covers the Earth, there are many Things mixt, which don't belong to the Air; and that therefore we must attribute no Properties to it, except those, which belong to it, when all these Things shou'd be separated from it.

2079. But we have clearly explain'd what we understand by Air*;
* 2076. namely this mixt Fluid, by which the Earth is surrounded. And we look upon those Parts only as not belonging to it, which are thicker, and can't be rank'd among the Parts of the Fluid, but float in it.

DEFINITION 1.

2080. *All the Air which the Earth is encompass'd with, consider'd together, is call'd the Atmosphere of the Earth, or simply, the Atmosphere.*

DEFINITION 2.

2081. *The Height of the Air above the Surface of the Earth, is call'd the Height of the Atmosphere.*

2082. That there is a Body every where on the Surface of the Earth, though it's Parts generally escape the Sight, is discover'd by Experiment*.

* 24.
2083. *That it yields to any Impression, and has it's Parts easily mov'd, is not doubted by any one.*

2084. *That it is heavy, is prov'd by its pressing upon the Surface of other Fluids, and sustaining them in Tubes.*

EXPERIMENT 1.

2085. Take a Glass Tube A B, about three foot long, of about $\frac{r}{4}$ Inch Bore; if you stop up the End A, and let the Tube be fill'd with Mercury, and let the other End be immersed in a Vessel, that has Mercury

Pl. 63. F. 1.

Mercury in it, the Mercury will be sustain'd at the Height of about 29 Inches.

This is occasioned by the Pressure of the Air upon the Surface of the Mercury in the Vessel; which cannot be pressed equally in every Part, unless in the Tube, where no Air is, there be a Column of Mercury, which presses equally with the outward Air *. This is called the *Torricellian* Tube, from *Torricelli*, who was the first that made this Experiment. 2086. 1416.

EXPERIMENT 2.

That this Pressure may not be chang'd when the Tube is inclin'd, it is requir'd that the Mercury should keep the same perpendicular Height*: If therefore there be two Vessels containing Mercury, in which Tubes in the Manner abovemention'd are immers'd, of which ED is inclined to the Horizon, the Mercury is sustain'd at the Heights *bf* and *ig*, so that *f* and *g* are in the same horizontal Lines; supposing the Surface of the Mercury in the Vessels to lye in the same Plane. 2087. Pl.63.F.1. 1423.

EXPERIMENT 3.

The same Pressure of Air sustains the Water of the Glass V, which is immerg'd in Water and filled with it, and then is pull'd out all but the Orifice, which still remains immers'd. 2088. Pl.63.F.2.

Water wou'd be sustain'd in the same Manner tho' the Height of the Glass should be 32 Foot; for Quicksilver is almost 14 times heavier than Water *, and a Pillar of Water a little more then 32 Foot high presses equally with a Column of Mercury 29 Inches high, which Pressure is equal to the Pressure of the Atmosphere. 2089. 1563.

EXPERIMENT 4.

In the Glass A, inverted, a Fluid, as Water, would be sustain'd by the Pressure of the Air, unless, by the Water's descending, the Air should ascend along it into the Glass; for this Reason if the Glass, before it be inverted, be cover'd with Paper, the Water is kept in, and the Paper is applied fast to the Water, by means of the Pressure of the Air. 2090. Pl.63.F.3.

That the Pressure of the Air depends upon it's Height, may be easily deduced from what has been said; but it is immediately prov'd by carrying the *Torricellian* Tube mention'd to a higher Place; for, when you carry this Machine up a Hill, for 100 Foot that you rise perpendicularly, the Mercury descends about an eighth of an Inch. 2091.

2092. That *Air presses equally every Way*, appears from this, that the Pressure is sustain'd by soft Bodies without any Change of Figure, and brittle Bodies without their breaking, tho' this Pressure be equal to the Pressure of a Pillar of Mercury 29 Inches high, or a Height of Water of 32 Foot *; any Body may see that nothing can preserve these Bodies unchang'd, but the equal Pressure on all
- * 2089. Parts; but it is plain that the Air does press in that Manner*. If
- * 1471. you take away the Air on one Side, the Pressure is sensible on the
1473. opposite Side.

EXPERIMENT 5.

2093. If the Tube A B, in which Mercury is sustain'd at the Height *f*
Pl.63.F.1. by the Pressure of the Air, whilst the upper Part is left empty *, be
- * 2085. raised a little, so that it's End may remain immerfed, it resists very much; if, the Mercury being thrown out, the Tube contains Air, it only resists by it's Weight, when it is lifted up.
2094. The Mercury cannot load the Tube; for it's Action against the Sides of the Tube is horizontal: But the Air acts against the upper Part of the Tube, and the Column, which is sustain'd by the Tube, is of equal Weight with the Column of Mercury, contain'd in the Tube. If, the Mercury being taken away, the Air be let in, as only the Tube loads the Hand, it appears, that the Action of the Air against the lower Surface of the upper Part of the Tube, destroys the Action against the outward Surface of the same Part of the Tube, and that the Air presses equally upwards and downwards.
2095. By this Experiment also, those Things are confirm'd, which are said concerning the Gravity of the Air.

C H A P. II.

Of the Elasticity of the Air.

2096. WE have seen, that the Air has the Properties of other Fluids;
- * 2075. but besides, it has another Property, as was said *; which is, that it can take up a greater or less Space, according as it is compress'd with a different Force; and, as soon as that Force is diminish'd, it expands itself. By Reason of the Analogy of this Effect with the Elasticity of Bodies, this Property of the Air is call'd it's Elasticity, and the Fluids, which have it, are call'd elastic Fluids, as has been already said.

Chap. 2. of Natural Philosophy.

5

That *the Air may be compress'd*, appears from an Experiment already mention'd *. And that *it may be dilated*, is prov'd from the following one. 2097.
* 24.

EXPERIMENT I.

Take the Tube A B clos'd at the End A, and pour Mercury into it, so that there may be some Air left in the Tube, which, when in the State of the external Air, will take up the Space A l; if the End B of the Tube be immers'd into Mercury, the Mercury in the Tube will descend to g, and there remain. The Height i g differs very much from the Height of the Mercury in the first Experiment of the foregoing Chapter. 2098.
Pl. 63. F. 4.

This Difference does not arise from the Weight of the Air in the Tube; for its Weight is too little to produce any sensible Difference in the Height of the Mercury; therefore the Action of the Air upon the Mercury must be attributed to another Cause. 2099.

The Force, by which the common or external Air is compress'd, is the Weight of the whole Atmosphere, which is equal to a Pillar of Mercury of the Height b f (Fig. 1.); therefore the compressing Force may be express'd by this Height. But now the Pressure of the Atmosphere exerts two Effects, it sustains the Pillar of the Mercury i g, and acts upon the Air in the Tube. *If the Force, by which the Mercury is sustain'd, at the Height g i, be subtracted from the Pressure of the whole Atmosphere; that is, if the Height g i be taken from the Height b f, there remains the Force by which the Air is compress'd in the upper Part of the Tube.* 2100.

This Air resists with the same Force, and presses downwards *: but it can't resist, unless it be retain'd *, and extends itself to A, and takes up the whole Space A l. * 361.
* 362.

But we find by Experiments, that *the Air dilates itself, in such Manner, that the Space, occupied by it, is inversly as the Force, with which it is compress'd.* 2101.

A MACHINE,

Whereby the Dilatations of the Air, as also the compressing Forces, are compar'd with one another.

The Iron Pipe A B, three Foot long, whose Bore is three Quarters of an Inch, and which is clos'd at A, is at B put into the Wooden Cylinder C, joined to the Box or Vessel D, and is there fasten'd, the Diameter of the Vessel is about four Inches, and it's Height almost equal to it's Diameter. The Pipe is fill'd with Mercury in such manner, that it may be about half an Inch high in the Vessel. 2102.
Pl. 63. F. 5.

The

The Pipe, with the Vessel join'd to it, is applied to a Board or Frame EFG; the Surface of which has a Groove in it, to receive the Pipe, and the Board is perforated in the Place, that answers to the Vessel and the Cylinder.

The Surface of the Part FG of the same Board is also hollow'd before to receive the Ruler of Box LM, which is moveable in this Cavity in such manner, that it may be fix'd at different Heights, by means of a Screw, join'd to the Ruler, behind, at the Distance of six Inches from the End L, and which goes thro' a Hole in the Board.

A Copper Plate rs is join'd to the Side of the Ruler of Box, and made fast. The Breadth of the Plate exceeds the Thickness of the Ruler a quarter of an Inch, so that the Plate stands out beyond it, making a Right Angle with the Surface of the Ruler.

Along this Prominence is mov'd the Piece n , join'd to the Index q ; this is fasten'd by the Screw o , and is represented by itself at ONQ.

2103. We use moreover a Glass Tube, a little more than three Foot long, and which is clos'd at one End; part of this is filled with Mercury, so as not to exclude all the Air. The open End, the Tube being inverted, is immerg'd in Mercury, contained in the

* 2098. Vessel and Iron Pipe, as in the foregoing Experiment *.

As this Glass Tube is less or more thrust into the Pipe, the upper Part of the Tube, that has no Mercury in it, is greater or less; and is measur'd, if we apply this Part to the Ruler LM, which has a Groove in it, to receive this Tube, and is divided into smaller Parts, which answer to equal Parts of the Capacity of the Glass Tube.

2104. If this Tube shou'd be exactly cylindrical, these Divisions wou'd be equal, but as this seldom happens, I shall shew how the Divisions of the Ruler are mark'd.

The Tube PV is inverted, and applied to the Ruler, so that the external Surface of the End V of the Tube, may agree to the end L of the Ruler. A small Quantity of Mercury is pour'd in, whose Height, for Example, in the Tube, is equal to a quarter or a third of an Inch, and the Height, to which it comes, is mark'd on the Ruler; an equal Quantity of Mercury is again pour'd in, and a second Division is mark'd; and by continuing to do thus, the whole Ruler may be divided. The equal Quantities of Mercury are had, by weighing them.

2105. But it is tedious and difficult, to separate so many small Parts of Mercury in such Manner, that they may all be exactly of the same Weight;

Weight ; therefore, if the Tube be regular, that is, if it be a Portion of a truncated Cone, as often happens, and differs little from a Cylinder, which is easily had, we may make use of another Method ; because in this Case the Divisions are very nearly in arithmetical Progreſſion.

The firſt four or five Diviſions are to be mark'd, by the Method ſhewn ; becauſe whilſt the Tube is hermetically ſeal'd it does not keep the regular Figure : Then ten, or twelve Times the Quantity of Mercury is pour'd into the Tube, and the Diviſion is mark'd ; this is diſtant ten, or twelve ſmaller Parts from that laſt mark'd ; and by continuing to do thus, the reſt of the Ruler is divided in the ſame Manner into ſuch greater Parts, denoting equal Portions of the Capacity of the Tube. Then theſe greater Diviſions are ſubdivided geometrically in ſuch Manner, that all the ſmaller Diviſions are in arithmetical Progreſſion continued.

But we muſt firſt examine, whether the greater Diviſions mark'd are in arithmetical Progreſſion, if they are not, the geometrical Diviſion can't take place, by Reaſon of the Irregularity of the Tube.

EXPERIMENT 2.

We muſt firſt of all meaſure exactly the Height, at which the Mercury is ſuſtained in the *Torricellian* Tube *, whose upper End is * 2106.
well clear'd of Air. 2085.

Such a Quantity of Air as you pleaſe is left in the glaſs Tube, before it is immers'd in the Mercury *. * 2103.

This Tube is put into the Mercury as far as you pleaſe alſo, and the Ruler LM is faſten'd in ſuch Manner, that the End L may agree to the Surface of the Mercury in the Glaſs Tube. But the Index *q* is applied to the upper End of the ſame Tube, and answers to the Diviſion of the Ruler, denoting the Space LV, which is taken up by the Air in the Tube. The Height of the Point L above the Surface of the Mercury in the Veſſel, is meaſur'd in Inches and ſmaller Parts, and is ſubſtracted from the Height of the Mercury in the *Torricellian* Tube, and the Difference expreſſes the Force, that compreſſes the Air in LM *. The Situation of the * 1100.
Glaſs Tube is changed, the ſame Air remaining in the Tube, and the Force is meaſur'd again, which compreſſes the Air, as alſo the Space taken up by the Air. Then the Spaces taken up will be inverſly, as the compreſſing Forces.

Let the Height of the Mercury in the Barometer be 29,25 Inches ; 2107.
the Height of the Point L above the Surface of the Mercury in the Veſſel

Vessel 20,25 Inches; and L V 32 Parts. Now if the Glass Tube be drawn out of it's Sheath more, L is raised up; when the Height of this Point comes to 24,75 Inches, L V is 64 Parts. The compressing Forces are 9. and 4,5; the Spaces taken up 32, and 64.

This Experiment may very well be varied many Ways.

The same Rule obtains in compress'd Air.

EXPERIMENT 3.

2108. Pl.63.F.6. Take a Curve Tube ABCD open at A, and clos'd at D; let the Part BC be fill'd with Mercury, so that the Part CD may contain Air of the same State or Tenor as the external Air; therefore, the compressing Force is the Column of Mercury, whose Height is bf (Fig. 1.) and by this Height must this Force be express'd, as in the foregoing Experiment; but the Space taken up by the Air is CD. Pour Mercury into the Tube AB, that it may rise up to g , the Air will be reduc'd to the Space eD : Now the compressing Force is equal to a Column of Mercury of the Height fg , and also the Pressure of the external Air upon the Surface g of the Mercury; this Force is express'd by the Sum of the Heights fg in this Figure, and bf in Fig. 1. This Sum is always to bf (Fig. 1.) as CD to eD ; and again the Forces are inversly as the Spaces.

2109. * 1464. * 2101. * 361. 2110. *The Elasticity of the Air is as it's Density*; for this last is as the Space taken up by the Air *, and therefore as the Force compressing the Air *; which is equal to that by which the Air endeavours to expand itself *; but this Force is it's Elasticity.

Hence it follows, that the Air in which we live is reduced to the Density which it has near the Earth, by the Pressure of the superincumbent Air, and that it is more or less compressed, according to the greater or less Weight of the Atmosphere; for which Reason also the Air is less dense at the Top of a Mountain than a Valley, as being compress'd by a less Weight.

2111. *The Force, by which the Particles of the Air fly from each other, encreases in the same Ratio, as the Distance between the Centers of the Particles is diminished.* That is, that Force is inversly as this Distance.

2112. Pl.63.F.7. To demonstrate which, let us consider two equal Cubes A and B, containing unequal Quantities of Air; let the Distance between the Center of the Particles be as 2 to 1, the Numbers of the Particles will be in the same, but inverse Ratio, in the Lines de and hi ; the Numbers of the Particles acting upon the Surfaces dg and hm are, as 1 to 4, namely, as the Squares of the Numbers of the Particles in

in equal Lines, and as the Cubes of those Numbers, that is, as 1 to 8, so are the Quantities of Air contained in the Cubes ; in which Ratio also are the Forces compressing the Air in the Cubes *. The Forces acting upon the equal Surfaces dg and bm are as the Forces by which the Air is compressed * ; they are also in a Ratio compounded of the Numbers of the Particles acting, and the Action of all the Particles ; therefore, this compound Ratio is the Ratio of 1 to 8 : The first of the compounding Ratios, as has been said, is that of 1 to 4 ; wherefore, necessarily the second is that of 1 to 2, which is the inverse Ratio of the Distance between the Particles. And this Demonstration is general ; for by 1 and 8 we express any Cubes whatever ; by 1 and 4, the Squares of the Cube Roots ; and lastly, by 1 and 2, the Roots of those Cubes.

* 2109.
361.
* 361.

This Demonstration proves that the Action, which the Particles continually suffer from all Sides, is encreased in the Ratio, in which the Distance between the Centers of the Particles is diminished.

2113.

But Experiments shew that the Particles do not extend their Action to Particles, remov'd to a sensible Distance ; whence it appears, the same Density of Air being suppos'd, that there is not a greater Elasticity, where there is a greater Quantity of Air.

2114.

The Effects of the Elasticity of the Air are like those of it's Gravity, and included Air acts by its Elasticity, just as Air not included does by it's Weight.

2115.

The Air which is loaded by the Weight of the whole Atmosphere, presses every Way from the very Nature of Fluidity * ; and the Force which it exerts, does no Way depend upon the Elasticity, because, whether you suppose Elasticity, or not, that Force which arises from the Weight of the Atmosphere, and is equal to it, can be no Way changed. But, as the Air is elastic, it is reduced to such a Space by the Weight of the Atmosphere, that the Elasticity, which reacts against the compressing Weight, is equal to that Weight *. But the Elasticity encreases and diminishes as the Distance of the Particles diminishes or encreases *, and it is no Matter, whether the air be retained in a certain Space by the Weight of the Atmosphere, or any other Way ; for in both Cases it will endeavour to expand itself with the same Force, and press every Way. Therefore if the Air near the Earth be inclosed in any Vessel, without altering it's Density, the Pressure of the included Air will be equal to the Weight of the whole Atmosphere.

* 1418.

* 361.
* 2109.

EXPERIMENT 4.

2116. Pl.68.F.I. The *Torricellian* Tube is enclosed in the Glass DR, so that the Air, which presses upon the Surface of the Mercury, contained in the Vessel V, may have no Communication with the outward Air; by the Elasticity of the Air the Mercury is sustain'd at the same Height in the Tube, as in the open Air.

The Tenor of the Air continuing the same, what we have said will always obtain; but this Tenor or Temper of the Air is not always the same; *the repellent Force of the Particles is often encreas'd, or diminish'd, though the Distance between the Centers is not chang'd;*

* 2123. I shall speak of this Alteration in the following Chapter*; in the following Part of this Book we shall also see, That the Elasticity encreases by Heat, and diminishes by Cold.

I shall deliver some other Experiments, concerning the Elasticity of the Air, in the fifth Chapter of this Book.

C H A P. III.

Of some other elastic Fluids.

2118. THERE are several Fluids, which have the same Property as the Air, Elasticity.

Among these Vapour is remarkable, of which we treat in the tenth Chapter of this Book.

2119. By *Fermentation, Effervescence, Putrefaction, and Combustion, elastic Fluids are separated from Bodies*, which are different according to the Difference of the Bodies.

2120. *Such a Fluid arises from many Bodies, when the Pressure of the external Air is diminished, or taken away.*

2121. *This is also observ'd in some, when they are only moisten'd.*

But in these two last Cases there is no Separation without Effervescence.

2122. All these Fluids, except Vapour, how different soever one from another, are commonly express'd by the same Name Air. But as *the Air is that Fluid, with which the whole Surface of the Earth is encompass'd*, this, properly speaking, is a Mixture made up of various elastic Fluids, in which innumerable Corpuscles of different Sorts float.

* 1476. These Corpuscles ascend to different Heights*, according to their different specific Gravity: and the Exhalations of different Bodies also, which are elastic Fluids, are rais'd differently in the Air.

1477.

Chap. 3. of Natural Philosophy.

II

Whence we infer, that *the Air in a high Place does not differ from the lower Air in Density only.* 2123.

It cannot be doubted that different elastic Fluids have different Properties; which also appears from Experiments; for the Effect of different Exhalations differ from one another. 2124.

Whilst the Parts, which, being separated from Bodies, make elastic Fluids, remain in the Bodies, they are join'd together, or adhere to other Parts of the Bodies; wherefore, they can't be rank'd among elastic Fluids any more, than Water, before it is turn'd into Vapour, can be call'd Vapour. 2125.

But the Space taken up, by the Matter which becomes elastic, is very small, whilst it remains in the Bodies themselves, if it be compar'd with the Space, which it takes up, whilst it exerts it's Elasticity, the external Compression being suppos'd equal in both Cases. 2126.

This plainly appears in those Bodies, which are wholly turn'd into an elastic Fluid. Ice a solid Body, whose Parts cohere, is first turn'd into Water, in which the Cohesion is less, then into Vapour, an elastic Fluid; this takes up a Space at least fourteen thousand times greater, than when it was Water; and this too whilst the Vapour is compress'd by the Weight of the whole Atmosphere; in those very Places from which it excludes the Air: and who does not see that this Expansion may be immensely encreas'd, by taking away the Pressure of the Atmosphere? 2127.

I shall make some other Observations concerning Water; an elastic Fluid may be separated from it without a sensible Diminution of it's Bulk; which Separation is made by Cold, Heat, or by taking away the Pressure of the Atmosphere. 2128.

We observe this Separation to be very sudden, if all the Pressure be suddenly taken away.

EXPERIMENT I.

The Glass Vessel A B is exactly fill'd with Water; at the End B a Brass Cylinder is join'd to it, that the Syringe, which is represented in Fig. 1. Pl. 71. may be join'd to it, by Means of a Screw. 2129. Pl. 63. F. 8.

Whilst the Piston of the Syringe is drawn out, the Water descends into the Syringe by it's Weight; and there is a Space in the upper Part of the Vessel void of Water and Air. Immediately also innumerable Bubbles of an elastic Fluid, shew themselves at the same Time; and all the Water looks white with these Bubbles.

This elastic Fluid differs from the Air, with which the Surface of the Earth is encompass'd, though it be in the Air in great Quantity. 2130.

EXPERIMENT 2.

2131. If a Phial be filled with Water, from which every elastic Fluid has been driven out, by Fire, or otherwise, and a small Bubble of Air being left, the Phial be inverted, and the open End of it be immers'd into Water, contain'd in any Vessel, this Bubble of Air, in some Days, will enter into the Water wholly, and several Bubbles will be successively absorb'd as it were by the Water in the same Manner. But with Respect to every one of the Bubbles it is to be observ'd, that a much greater Part of the Bubble enters into the Water the first Day, than there does in the following Days.

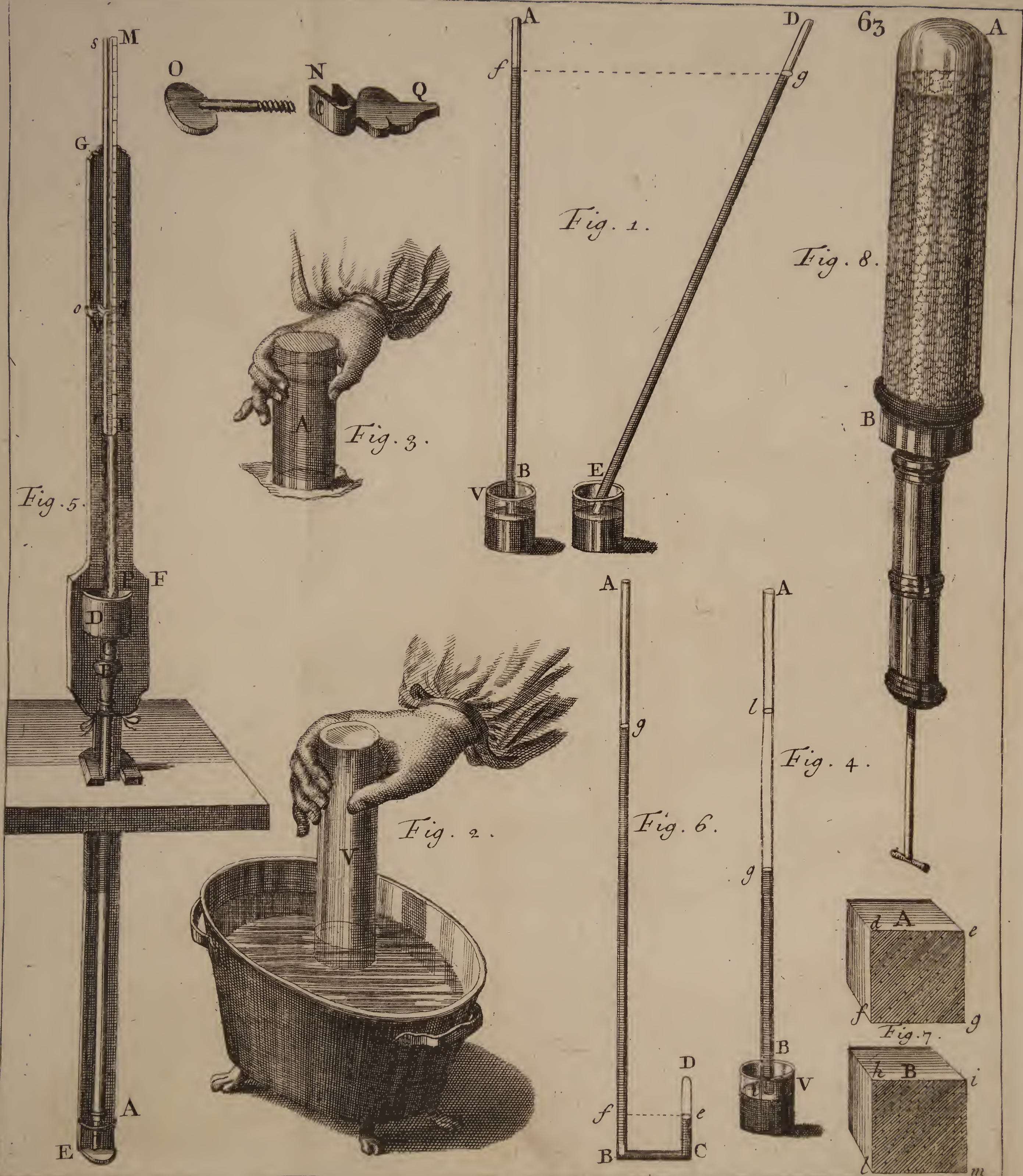
2132. From this Experiment we infer that there are some Parts in the Air, which enter into the Water more easily than others, and remain there.

Whence it follows that, whilst Water is expos'd to the open Air, there enters into it a greater Quantity of that Matter, which gets into it more easily; and that the Air, that has enter'd into it, differs from the external Air. We observe also that this Fluid often dilates itself more, when the Pressure is diminish'd, than according to the Rule of Number 2101. But the Expansion of this Fluid is immense.

2133. This Fluid takes up a very small Space in the Water; for, as was said above, the Separation is made without any sensible diminution of the Bulk of the Water, and *Mariotte* mentions an Experiment concerning the Dilatation of this elastic Matter, whereby it appears, that this Matter, which was driven out from the Water, when it had lost it's Heat, and sustain'd the Weight of the whole Atmosphere, took up ten times the Space, that the Water did, in which it had been contained.

2134. In the fifth Chapter of this Book we shall see *, how much this Fluid can be dilated; if it expands itself ten thousand times only, it's Space will be an hundred thousand times greater than the Space taken up by the Water from which it went out. But who shall determine how great the Expansion is, if we have Regard to the Space taken up in the Water by this elastic Matter?

* 2196. Hence we infer, that *the Particles of elastic Fluids* are not of the same Nature with other elastic Bodies; for all the Particles cannot be encreas'd, as the whole Bulk is encreas'd, the Surface, in every Degree of Expansion, being kept free from all Irregularities and Angles, for in Expansions the Parts are easily mov'd amongst themselves: Whence it follows, that the Particles *do not touch, tho' they*



they repel one another, a like Property of Particles has been taken Notice of above *.

* 75. 87.

C H A P. IV.

Of the AIR-PUMP.

THE Elasticity of the Air is the Foundation of the Construction of a Machine, by which the Air may be drawn out of any Vessel. This Machine is called an *Air-pump*, which is made several Ways.

2136.

The chief Part in all of them is a Barrel, or hollow Cylinder of Metal, polish'd in the Inside; in this Barrel must move a Piston, that fills it's Bore so exactly as to let no Air slip by. This Piston is thrust down close to the Bottom of the Barrel, and then rais'd up in such a Manner as to exclude all the Air from the Cavity of the Cylinder or Barrel; if this Cavity communicates with any Vessel, by Means of a Pipe at the Bottom of the Barrel, the Air in the Vessel will expand itself, and Part of it will enter into the Barrel, so that the Air in the Barrel, and in the Vessel, will have the same Density. Shut up the Communication between the Vessel and Barrel, and letting the Air out of the Barrel, apply the Piston close to the Bottom. If you raise the Piston a second time, and open the Communication between the Barrel and Vessel abovementioned, the Density of the Air in the Vessel will again be diminish'd; and repeating the Motion of the Piston, the Air in the Vessel will be reduc'd to the least Density. Yet all the Air can never be exhausted by this Method; for at every Stroke the Air does so expand itself, as to have the same Density in the Barrel as in the Vessel; in which last therefore, there is always a little Air left.

But after the Elasticity is diminish'd, as much as possible, by repeating the Operations, we ought not from hence to make a Judgment of the Density, as in smaller Dilatations *. This Elasticity of the remaining Air is not always the same, and it is not sensibly diminish'd by the Dilatation of it, as we shall find in the following Chapter *.

2137.

* 2109.

* 2191.

2138.

All Air-pumps have in common the Parts above describ'd, but they differ in several other Things. First, the Communication between the Receiver to be exhausted, and the Cylinder or Barrel, is open'd and shut different Ways. Secondly, there are different Ways of getting the Air out of the Cylinder or Barrel, when the Piston

Piston is brought to the Bottom. Thirdly, the Pistons differ in different Pumps. Fourthly, the Position of the Cylinder is not the same in all Pumps. Fifthly, there are different Contrivances for moving the Piston. Lastly, there are often two Barrels, in one of which the Piston is rais'd, when it is depress'd in the other.

Pl. 64. Our Pump is here represented; the opposite Part of the Box, or Case, the Door being shut, which belongs to that Part, is seen in Fig. 1. Plate 68. I shall defer the particular Description of it to another Place, and only here mention some Things in general.

The A I R - P U M P.

2139. The fore Part of the Pump is represented in Plate 64. the Doors
Pl. 64. of the Box, in which it is enclosed, being taken away.

Pl. 65. The hinder Part of the same Pump, taken out of it's Box, is represented in Plate 65. The same Parts are mark'd with the same Letters in each Figure.

This Pump has two Barrels A, B, in each a Piston is mov'd, whose Parts are represented separately at C, D, E, and F.

2140. To the lower Plate of the Part D, there is joined a small square Tube *d*, to whose Cavity the Hole *n* in the Plate answers.

This small Tube goes through the Cylinder F of Cork, which is retain'd by the Plate E, with which the solid Piece *g* coheres, which goes into the small Tube *d*, and is fasten'd by the Screw *e*, which goes into the solid Piece, and whose Head at *n* covers the Hole, which answers to the Tube *d*. Between the Plate E and the Cork F a thin Piece of Leather *f* is fasten'd, which is prominent every Way, and which, whilst the Piston is thrust into the Cylinder, applies itself to the lateral Surface of the Cork. This Method is used in *England*. This Leather shou'd be soak'd in Oil and Water, as was said in N. 1436.

The Pistons before they are thrust into the Barrels, should be left in Water some Hours, and well oil'd. A small Quantity of Water must be pour'd into the Barrels upon the Pistons.

2141. We make use of Calf's Leather, we apply the Epidermis to the Cork; but Care must be taken, that the Piston exactly fills the Barrel, but yet so, that the Leather may not be compressed too much; for if it be made dry, whilst the Oil and Water are squeezed out by a too great Compression, the Pistons will not retain the Water, when it sustains the whole Pressure of the Atmosphere. But when the Leather is of a due Thickness, we may make use of the Pump two or three Months, without once taking
out

out the Pistons: Which yet we should not neglect, when, the Oil being grown thick, the Leather adheres to the hollow Surface of the Barrel, and the Pistons are mov'd with Difficulty: Then they must be taken out; the Leather must be separated a little from the Cork, and well oil'd, and the Pistons must be left some Hours in Water.

The Tail C of the Piston has Teeth, as in most Air-pumps; its lower End *c* is cylindrical. This cylindrical Part passes through a cylindrical Cavity in the Prominence *p* of the Piston; the Diameter of this Cavity exceeds the Diameter of the Cylinder *c* but a little, and the Tail C may be rais'd, and depress'd, three Quarters of an Inch, the Piston itself remaining unmov'd.

2142.

Both Pistons are mov'd by turning the Wheel R, whose Motion, whilst it goes and comes, wants somewhat of the third Part of a Circle.

Pl. 64.
65.

The Vessels to be exhausted are put upon the Plate G, and this communicates by the Pipe XXX with the Barrels. For there is a Cavity under the Plate C, which answers to the Pipe II, in which there are two Cocks, Y, Z, between which the Pipe XX is join'd to this Pipe which communicates with them, under the Plate, upon which the Barrels stand.

2143.

There is a Cock under the Bottom of each Barrel; the Tails of these Cocks are seen at L, L, which are join'd by the Brass Ruler PP in such Manner, that by the Motion of this Ruler both the Cocks may be mov'd at the same Time. To the Axis of the Wheel R, behind, is join'd an Iron cross Piece H N M, whereby these Cocks are mov'd.

2144.

In the Position, in which the Parts of the Machine are represented in this Figure, the Barrel B communicates with the Vessel to be exhausted; the Barrel A with the external Air; and, by depressing the Piston of this Barrel, all the Air is forc'd out of it, and in the mean Time the other Piston is rais'd higher.

The Air, which is forc'd out of the Pump, goes out through the Cock at *l*, where there is a Prominence, that a small Valve made of Leather may close the Hole. This Valve hinders the entring in of the external Air, and we may do without it; but it very much lessens the Labour.

2145.

When the Piston comes to the Bottom of the Pump A, the End N of the Cross passes over the Roller *v*, which it depresses, raising the End S of the smaller Iron Ruler S V, which moves about the Tail *o*, which coheres with it, and goes through the Cylinder O in the

2146.

the Middle of the Ruler P P, join'd to it; S V immediately returns to it's former Position, and in that very Moment the Piston is applied to the Bottom of the Pump.

2147. The Motion of the Wheel is now to be directed towards the contrary Part. In the Return of the Cross the End N runs against the Roller *v*, and drives it on; 'till this Roller is so depress'd, by turning the Cocks L, L, that N passes over it.

In this turning of the Cocks, L, L, they describe Arches, of ninety Degrees; and the Communication of the Barrel B with the Vessel is stopp'd, and a new Communication with the external Air is open'd; the contrary to this obtains in respect of the Barrel A.

During this Motion of the Cocks, C is indeed rais'd, but the Piston itself remains at the Bottom of the Barrel A; which is necessary lest the external Air shou'd again enter into the Barrel, and which how it is done has been said above*.

* 2142.

Now if the Motion of the Wheel be continued, the Piston of the Barrel A is rais'd up, which communicates with the Vessel to be exhausted, and the Air is forc'd out from the Barrel B, and the End M of the Cross passes over the Roller *v*, and what was explained in the contrary Motion, obtains in this Case, in the same Manner.

2148. The Wheel is turn'd by the Handle *mm*, which is about two
Pl. 64. Foot long; this is in an horizontal Position, when the Ends M, and N, of the Cross, are also in an horizontal Line.

2149. When in this Motion it happens, that there is a greater Resistance, when the Cocks are mov'd, than in the rest of the Motion, this is a Sign that the Cocks want to be rubb'd with Oil and Wax; which in hot Weather shou'd be repeated, when the Machine has been in continual Motion, for three or four Hours.

2150. As to the Cocks Y, Z, above-mentioned*, by the first the Com-

* 2143. munication between the exhausted Vessel and the Barrels is stopp'd, when the Air is exhausted; by the other, the Air is again let into the Vessel, and the Communication with the mercurial Gage is cut off.

2151. This mercurial Gage is represented at Q; it's Use is to determine the Quantity of Air exhausted from the Vessel, as also the Quantity of Air that remains in it; by this also the Capacities of Vessels to be exhausted are measur'd; which is of Use in many Experiments. Mine differs from the common Gages.

2152. There is a Pipe at K that has a Hole at it's upper End, and a Screw at it's lower End, it goes into the Plate G, and the Air passes through it into the Pump.

In

In the same Manner, a small Cylinder, with a Screw upon it, is frequently join'd to the Plate of the Pump, whereby a Globe, or any other Vessel to be exhausted, may be applied to the Machine; which is commonly done by putting a Cock between, that the Vessel when emptied of the Air may be separated from the Pump.

2153.

In the Middle of the Plate G there is a Hole at *a*, whereby several Machines may be joined to the Plate; and which is clos'd by a Screw.

2154.

By this Means also there is often applied to the Pump a cylindric Box, full of Leathers waxed, through the Center of which a Brass Wire passes, which may be mov'd by the Help of a Handle, so as to communicate Motion into a Place void of Air; the Box has a Cover, which enters into it with a Screw, for pressing the Leathers together, and the better to prevent the passing by of the Air.

2155.

Such a Box, or Collar of Leathers, is often join'd to the Cover which is laid over the Receivers, as may be seen in Fig. 3. Plate 3. and in many Plates of this Book.

When the Receivers are laid upon the Plate G, or when they have Covers, and the Air is to be kept from getting in, some Hours, or Days, we make use of a Mixture made up of four Parts of white Wax, two of Refin, and one of Oil of Olives; in Summer less Oil is requir'd, in Winter more.

2156.

For a less Time it is sufficient to put the Vessels upon a Ring of thin Leather, which has been soak'd some Days in Oil; it must be well oil'd every Time, before it is us'd, and left in Water a Quarter of an Hour; but when the Experiments are ended, the Leather must be well dry'd with a Linen Cloth; and the same Ring may serve many Years, if it be kept in a dry Place.

2157.

A single barrel'd Air-pump.

I shall briefly shew how many Conveniencies of our Pump, may be transferred to a less, and single barrel'd Pump.

2158.
Pl. 66.

This Pump consists of one Cylinder A; which is applied to the vertical Board or Frame B B.

The Piston is like that, which has been explained above*, the Tail of it has Teeth also, and is moved by Means of a Sector of a Circle which has also Teeth. The Motion is impress'd by moving the Handle *m m*, join'd to the Axis which passes through the Center of the Sector.

2140.

2159. To the other End of this Axis is join'd the Iron Crofs K P O, by Means of which the Cock of the Barrel is moved, which is applied beneath the Bottom of it. L is the Tail of the Cock, which is equally extended both Ways, and to which, at the upper End of it, is join'd the Roller *v*, and the Piston stands upon the lower End of it.

* 2144. In the Position of the Cock, which is represented, there is a Communication between the Pump and the external Air, through an Hole at *l*, through which the Air goes out *, whilst the Piston is deprests'd.

When the Piston is but a little distant from the Bottom of the Barrel, M passes over the Roller *v*, and when it has pass'd over, O is applied to the Part *s*, and pressing it, it lifts up the Roller *v* a little; whereby the Position of the Cock is indeed alter'd, but the Way, through which the Air comes out, is not much narrow'd. In this Position the Piston is applied to the Bottom, and no Air remains in the Pump.

2160. The Motion of the Sector is now directed towards the contrary Part; M runs against the Roller *v*, and turns the Cock, and the

* 2147. Piston is rais'd *. When the Piston is almost come to the Top of the Barrel, the Parts N and P of the Crofs act, as M and O acted, before; the Cock is turn'd anew, the Motion of the Sector being alter'd.

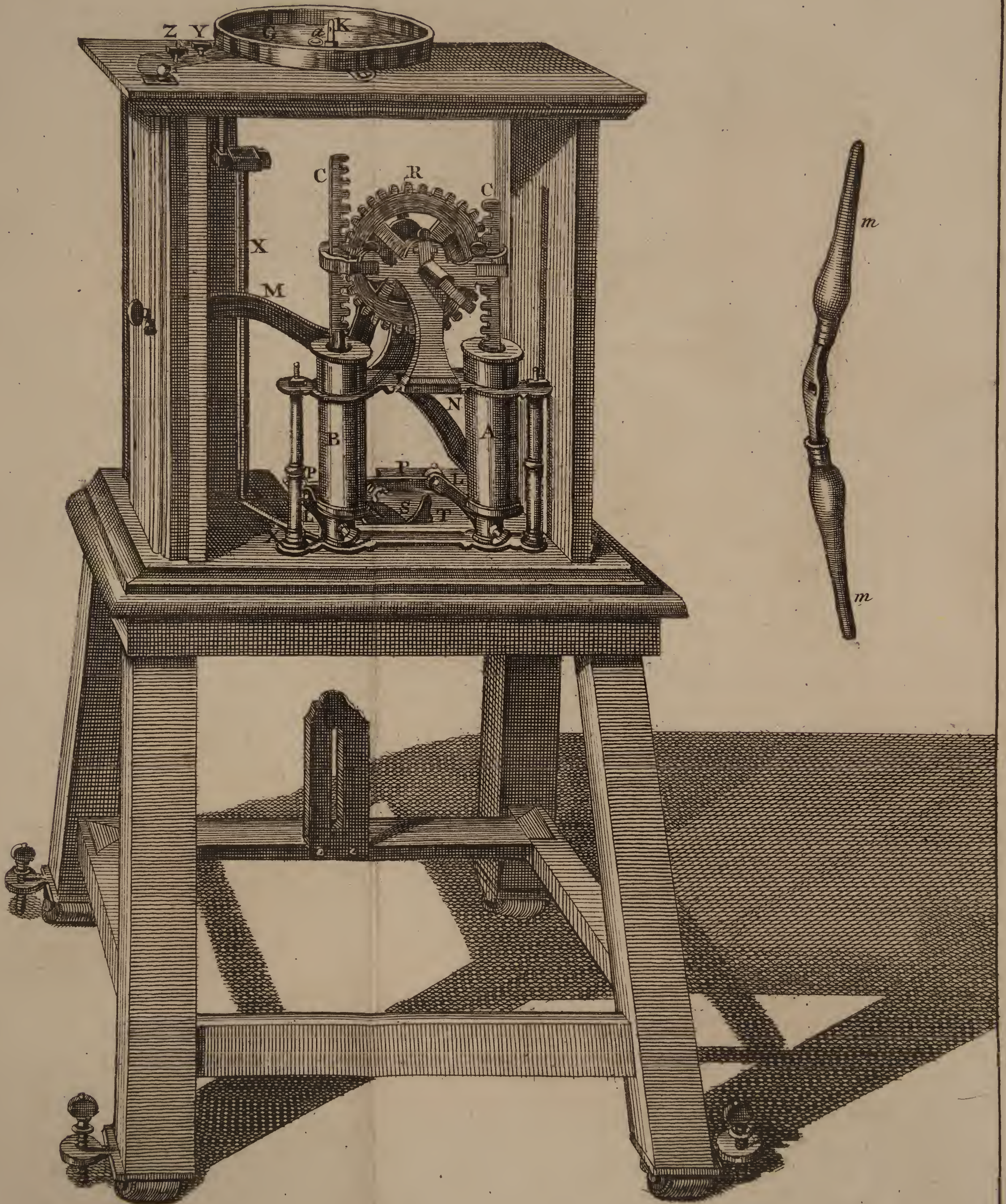
During the Ascent of the Piston, the Barrel communicates with the Vessels to be exhausted, by Means of the Pipe X X, which

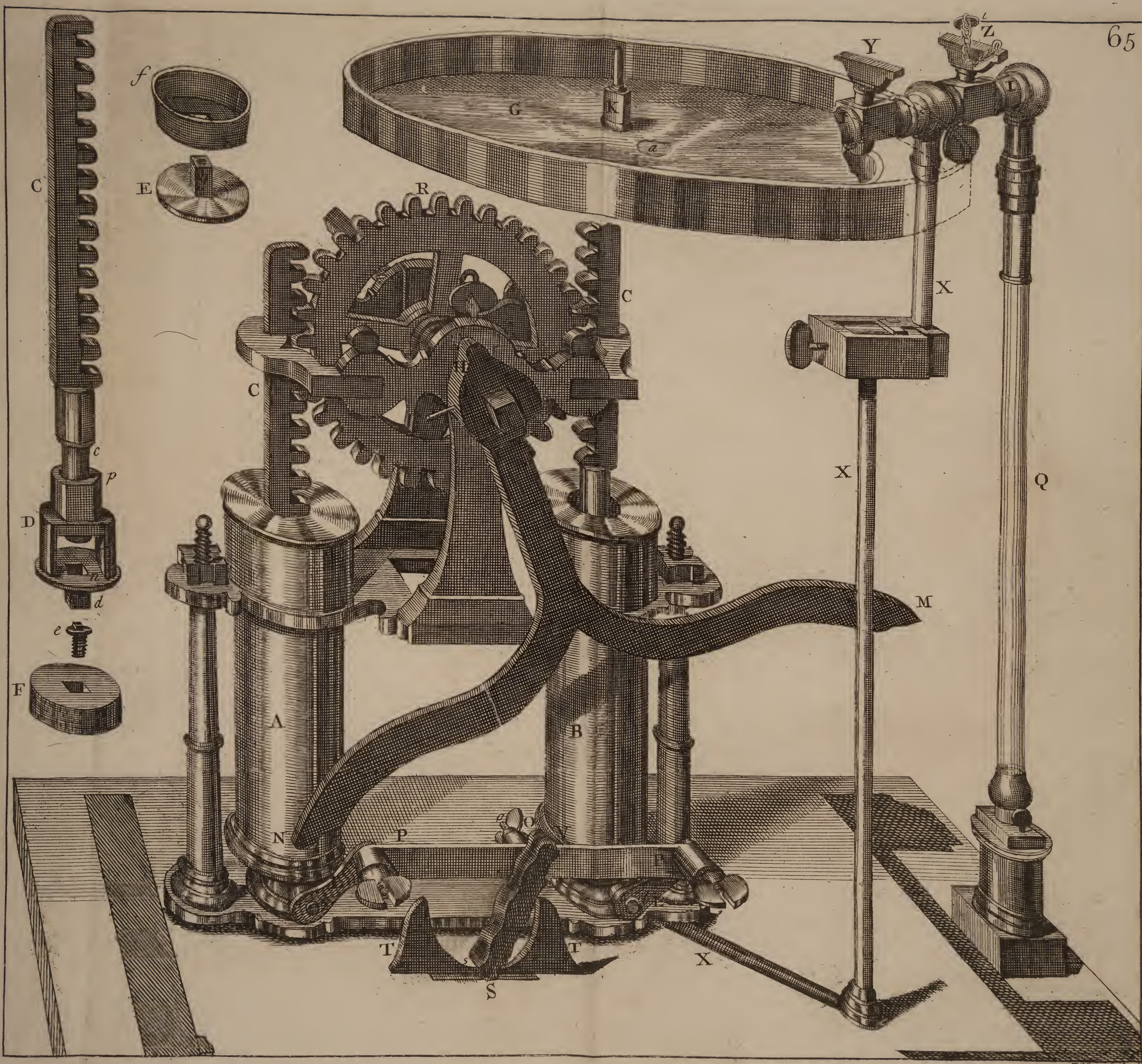
* 2143. Vessels are put upon the Plate G *, or are join'd to the Pump at
* 2153. K *.

2161. By the Cock Y the Communication between the Pump and the Vessels to be exhausted is stopp'd, and the Air is let into them again also.

2162. The mercurial Gage Q has the Uses already mention'd *; that
* 2151. represented here is a plain and simple one, consisting of a Glass Tube, above three Foot long, and whose lower End is immers'd in Mercury. The Gage represented in Plate 65 may be used here also.

What is contain'd in Numbers, 2152, 2153, 2154, 2155, 2156, and 2157, should be referr'd hither also.





C H A P. V.

Several Experiments concerning the Air's Gravity, and it's Spring.

WE have shewn that Air is heavy *; it may be weigh'd like
other Bodies, and so it's Density may be compar'd with *
that of other Bodies *. If the Vessel that contains the Air be *
weigh'd, when it is full of Air, and again, when the Air is exhausted,
the Difference between their Weights is the Weight of the Air.
But we shou'd make use of a very nice Balance.

2163.
2084.
1463.

EXPERIMENT I.

Having exhausted the Air out of the Glass Ball G *, whose solid
Contents are 283 cubic Inches. This is suspended on the Arm B
of the Balance A B; Weights are put into the Scale L, to make
an Equilibrium. The Cock E being open'd, the Air enters in, and
the Equilibrium is destroy'd; but it is restor'd, if about an hundred
Grains be added to the Weight in the Scale; sometimes the num-
ber of Grains, which are added, is greater, and often less, accord-
ing to the different Temper of the Air, which undergoes Alterations,
from the Alteration of the Weight of the Atmosphere, and from
other Causes.

2164.
Pl.67.F.1.
2153.

We have seen that Bodies immersed in Fluids are sustain'd by
them, and more or less according to the greater or less Bulk of the
Body *; and the Weight lost in that Case is determin'd from the
known Density of the Fluid *. By the foregoing Experiment, there-
fore, it may be known, how much Bodies gravitate less in Air than
in a Vacuum.

2165.
1495.
1478.

Hence also may be deduc'd, that *Bodies that are in Equilibrio in
the Air, if their Bulks are unequal, will lose their Equilibrium in a
Vacuum*, which is confirm'd by the following Experiment.

2166.

EXPERIMENT 2.

The Copper Plate *e i* is applied to the Plate G, of the Air-pump,
and is fasten'd by Means of the small Tube K, whose Screw goes
through the Plate. To this Plate at *i* there is fasten'd a short
Cylinder, to which the Copper Plate F H is join'd, which hinders
the Bodies, made Use of in the Experiment, from touching the
Leather Ring *, applied to the Plate G, in their Motion.

2167.
Pl.67.F.2.
2157.

At the End *e* of the same Plate, a thick Brass Wire stands upon it, which is bent at Top, that the Plate L may be vertically join'd to it, which has a Hook at Bottom, and which can be rais'd, and depress'd, and fix'd by Means of the Screw *n*.

A small and very exact Balance is suspended upon this Hook; the Solid D of Wax and the Leaden Weight, which together with their Chains are in Equilibrio, are hung upon the Balance; and the Plate L is fix'd at such an Height, that the Balance can only move a little.

All these Things are cover'd with the Glass Receiver R, and the Air being exhausted, the Wax preponderates, it's Bulk being greater than the Bulk of the Piece of Lead P, it must be more sustain'd by the Air; when you let the Air into the Receiver again, the Equilibrium is restor'd.

2168. The Elasticity or Spring of the Air which has been prov'd in the second Chapter of this Book, becomes more sensible by the following Experiment.

EXPERIMENT 3.

2169. Tie up a Bladder very close, with a small Quantity of Air in it, put a Receiver over it, and pump out the Air; thereby the Pressure upon the External Surface of the Bladder will be diminished; and immediately the Air included in the Bladder will expand itself, and swell it out.

* 2170. We have seen that the Spring of the Air is equal to the Weight
* 2115. of the whole Atmosphere*; the following Experiment will make it visible.

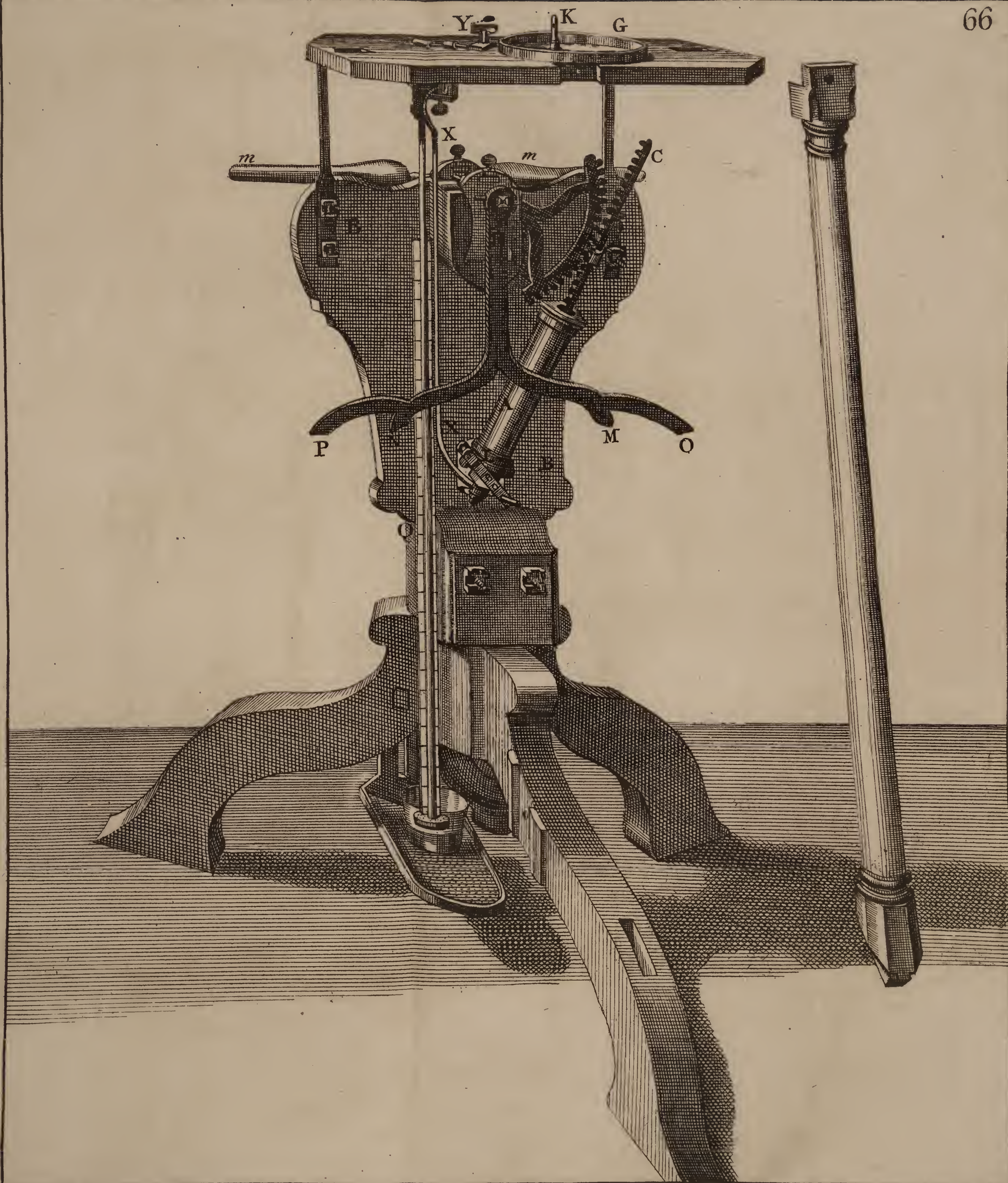
EXPERIMENT 4.

2171. Take a Bladder tied up very close, and not quite full of Air, and
Pl.67.F.3. put it in the Bottom of the Wooden Box A, whose interior Diameter is three Inches. Put on the Leaden Weight P, which weighs forty Pounds, and goes into the Box, only leaving Room for the Bladder.

Cover the Box with a Glass Receiver, pretty high, that the Weight P may be raised an Inch high.

The Air being exhausted, the Bladder, as in the foregoing Experiment, will swell out, whereby the Weight will be rais'd: if the Weight were as big again, it wou'd be rais'd in the same Manner.

2172. In the following Experiment we observe the Effects of the Gravity of the Air and it's Spring at the same Time.





EXPERIMENT 5.

To the Hole *a* in the Middle of the under Side of the Plate G of the Air-pump, screw on the hollow Brass Cylinder B. This Cylinder coheres with the Glass Tube T, open at both Ends, whose lower End is immerg'd in Mercury, contained in the Box P. The Mercury is sustained in the *Torricellian* Tube *ig*, as was said before *. The Vessel V, together with the Tube, is put upon the Plate G, and covered with the Glass Receiver R. The Receiver is open at Top, and has the Brass Cover E, to which the Cylinder C is join'd, into which is put the End of a wider Glass Tube D, which is clos'd at Top, and contains the Tube *ig*. By these all Communication between the outward Air and the Vessel V is taken away. The Air, in the Tube T, only communicates with the Air in the Receiver R and the Tube D, and by it's Elasticity hinders the Mercury from rising into the Tube, by the Pressure of the external Air; the Air also, inclos'd in the Receiver R, sustains the Mercury in the Tube *gi* by its Elasticity *. The Air must be drawn out from the Vessel R; whilst the Density decreases, the Elasticity decreases also *, and the Force, by which the Mercury is sustained in the Tube *gi*, is less; therefore the Mercury descends. At the same Time the Pressure of the external Air overcomes the Resistance in the Tube T; and the Mercury ascends into the Tube. The Diminution of Elasticity in the Tube T, and Vessel R, is the same, and the Effect of the Diminution in each Case is the same: Therefore the Mercury descends so much in the Tube *ig*, as it rises into the Tube T; which agrees with the Experiment. By this Method the Mercury is raised to *f*, whilst the Tube *gi* remains almost empty; the Air being again let in, the Mercury ascends into the Tube *gi*, whilst it sinks in the Tube T.

This Experiment confirms the Rule concerning the Elasticity of the Air, mentioned before *. The Diminution of the Quantity of Air, in every Motion of the Pump, follows the same Ratio; for the Air contained in the same Receiver, when the Piston is applied to the Bottom, is always to the Air, which remains in the Receiver, after the Motion of the Piston, as the Capacity of the Receiver, and the Part of the Barrel, which the Piston has left empty, to the Capacity of the Receiver alone.

Whence we infer, that the Quantities of Air, which remain after each of the successive Motions of the Pistons, are in geometrical Progression; as are also the Densities *, and the Elasticities †, which last is now to be confirm'd.

EXPERI-

EXPERIMENT 6.

2176. In this Experiment we make use of any Receiver whatever, but Pl.68.F.1. we must have the Tube T: In that which I shall now mention the Receiver was not very large.

After two Agitations of the Pump, that is, after one Motion of each Piston, the Height of the Mercury in the Tube T was 11, 1 Inches; again, after two Agitations the Height was 17, 85 Inches: Lastly, in two Agitations more it came to the Height of 22, 1 Inches.

The Height in the empty Tube was 29 Inches.

2177. Therefore the compressing Forces, which are equal to the De-
* 2100. grees of Elasticity, were 29; 17, 9; 11, 15; 6, 9 *; which Numbers differ little from a geometrical Progression: For if we seek two mean Proportionals between the first and the fourth, we have this Proportion, 29; 17, 97; 11, 14; 6, 9.

2178. In the fifth Experiment we said, that the Tube, enclos'd in the Receiver, was almost emptied of the Air; for if there should be no Air at all in the upper Part of the Tube, the Air can never be so taken out from the Receiver, as that there will be the same Height of Mercury in the Vessel and in the Tube; if this obtains, as sometimes happens to those, who are less careful, we may be certain, that there is some Air in the Tube.

2179. The Mercury which remains in the Tube, shews that there remains a Pressure upon the Surface of the Mercury in the Vessel.

2180. We have seen that all the Air can never be taken out of a Vessel, by repeating the Strokes of the Pump; but yet that it can be so

* 2136. diminished, that the Density will not be sensible *. But if we consider the Construction of Pumps, this is manifest enough; that, when the Piston is applied to the Bottom, all the Air can never be so thrown out, so that none at all will remain; whence it follows, 2181. that *the Density of the Air in the Vessel, which is emptied, cannot be*
2182. *diminished beyond a certain Degree*; yet, *if* we come to compute it, we find this Density so small, that *the Elasticity* wou'd be very little sensible, if it *shou'd be diminished with the Density*. If a six hundredth Part of the Air shou'd remain, and it appears that there often remains a less Part, *the Elasticity wou'd not sustain the Mercury at the Height of a twentieth Part of an Inch*. But we must determine nicely what the Elasticity is equal to.

2183. This is easily obtained, when in Exp. 5. we make use of the Terricellian Tube well emptied; for then the Height of the Mercury

cury in the Tube, after the Receiver is exhausted, immediately shews the elastic Force of the remaining Air ; but it is very difficult, before Immerfion, to fill the Tube with Mercury, so that no Air at all may remain in it.

We must then use the Barometer. The *Torricellian* Tube is so call'd, when it is applied to a Frame, on which are marked Divisions at the Side of the Tube, that the Height of the Mercury in the Tube may immediately be known. In the Construction of such an Instrument greater Care is taken, than in filling a Tube, which is made use of in one or two Experiments. Therefore if we have a Barometer, made by a good Workman, and in which the Divisions accurately shew the Height of the Mercury in the Tube, *the greatest Height, to which the Mercury can rise in the Tube T, will be to be subtracted from the known Height of the Barometer, and the Difference will express the Height, at which it can be sustained by the Elasticity of the Matter, remaining in the Receiver.*

But if we have not such a Barometer, we may make use of this Method. We may fill with Mercury a short Tube, about three Inches long, and immerge it in Mercury, contain'd in a Vessel, as was said of the *Torricellian* Tube * ; but a small Tube may more easily be fill'd nicely ; and when it is once prepar'd it is easily kept, to serve again, as often as you please ; that, which I make use of, has been fill'd above twenty Years. Along the Tube on one Side there is applied a Paper, on which is drawn a Line divided into Inches, and smaller Parts ; I made use of Rhinland Inches divided into Twelfths, which are call'd *Lines*. The Tube is fasten'd, that it may be vertical.

EXPERIMENT 7.

These Things being thus prepar'd, the small Vessel V with it's Tube A B, is covered with any Receiver whatever ; the Air being exhausted as much as possible, the Height of the Mercury is measured by help of the Divisions join'd to the Tube.

This Height is very different according to the different Temper of the Air, and always greater when it is moist. In which last Case the Height is sometimes seven Lines, that is, it exceeds half an Inch ; at other times, the Height is less than a Quarter of an Inch, but this seldom happens.

When, the Elasticity of the Air can be no further diminished, by repeating the Strokes of the Pump ; which is known, when the Mercury sinks no more in the said Tube, or when it is no longer rais'd

in the Gage of the Pump, we must not conclude, that the Density of the Air cannot be diminished any more.

2190. The Experiment concerning Sound, which we shall explain in
 * 2324. what follows *, evidently shews, that the Density is diminished, by continuing the Strokes of the Pump, whilst the Gage is not alter'd at all ; which follows, from a very remarkable Property of *the Matter, which remains in the Receiver* ; for this Matter, *although it be dilated, keeps it's Elasticity* ; as has been shewn above *, and is immediately demonstrated by Experiment.

EXPERIMENT 8.

2192. We make use of the same Tube A B together with it's small
 Pl.69.F.1. Vessel V, and us'd in the last Experiment, and cover it with a less Receiver, which may be done. The Receiver is so dispos'd, that it may inclose the Hole *a* in the Middle of the Plate G. Into this Hole is put the Screw, cohering with the Bottom of the Syringe P, which is join'd to the Plate by Means of it. The Piston fills the Syringe nicely, so that the Air cannot pass by ; but the Air can go freely through the Hole in the Bottom from the Receiver into the Syringe.

2193. The Air being exhausted, so that the Height of the Mercury in A B might be two Inches, I stopt the Communication between the Barrels, by which the Air is exhausted, and the Receiver ; but the Piston of the Syringe P being depress'd, the Descent of Mercury in the Tube A B was four Lines ; that is, it was equal to a sixth of the whole Height.

Continuing to empty the Receiver, the smallest Height, to which the Mercury in the Tube cou'd be reduc'd, was six Lines : The Communication with the Barrels, by which the Air is taken out, being now stopt again, and the Piston of the Syringe being depress'd, no Alteration at all cou'd be perceiv'd in the Height of the Mercury in the Tube ; according to the Rule * the Mercury shou'd have been depress'd the twelfth of an Inch.

2194. The elastic Matter, produced from Water, has this Property also, that the Elasticity is not diminished with the Density, as was said in N. 2131.

EXPERIMENT 9.

2195. A spherical Glass Vessel, which has a long Neck, is inclos'd in a higher Receiver (as the Upper Receiver R in Fig. 2. Plate 71.) and, the Air being exhausted, it is left for some time, that the greater Part of the Matter mentioned may go out of the Water.

The

The Receiver being taken away the Vessel is inverted, and the Aperture of the Neck is immerged in a Glass, containing Water, but which is also clear'd in Part of the said Matter. The Vessel remains full of Water *. This is covered with the Receiver together with the Glass; and the Air is drawn out, 'till the Surface of the Water in the Neck of the Vessel agrees to the Surface of the Water in the Glass. The Elasticity of the Matter remaining in the Receiver is measur'd *. This is equal to the Elasticity of the Matter, which, during the Evacuation, went out of the Water into the Vessel; for if this Matter shou'd not so press the Surface of the Water in the Neck of the Vessel, the Water by it's Pressure upon the external Surface wou'd rise into the Neck *. * 2088. 2185. 2186. 1416.

The Air being let into the Receiver, the Water rises into the Vessel, and the elastic Matter is reduc'd into a small Bubble; which if we measure, we find the Dilatation of the Matter in the Experiment; by comparing the Magnitude of the Bubble, with the Magnitude of the Vessel itself.

By such an Experiment we often find that such a Bubble is dilated ten thousand times, or fifteen thousand times, and more. 2196.

But the Elasticity in these Experiments is always sufficient to sustain a Column of Mercury, which is not less, and frequently greater, than an hundredth Part of that, which is sustained by the Weight of the whole Atmosphere. 2197.

By the following Experiments we shall illustrate some other Phenomena, which depend upon the Weight, or Elasticity of the Air. 2198.

EXPERIMENT IO.

If the Piston of a Syringe be applied to it's Bottom, and a Tube join'd to the Syringe be immerg'd in Water; the Water, if the Piston be rais'd up, will follow it, and fill the Cavity between the Bottom of the Syringe and the Piston. 2199.

It is manifest that this Ascent is to be attributed to the Pressure of the outward Air; for this Reason, the Water does not rise into the Syringe in a Vacuum; because this Pressure is wanting. 2200.

EXPERIMENT II.

Join the Glass Tube *bc* to the Syringe *A*, which is fasten'd to the Brass Cover *O*, with which the Glass *R* to be exhausted is cover'd, Pl.67.F.4. the End *c* of which Tube descends below the Surface of the Water, contain'd in the Vessel *V*; thrust down the Piston to the Bottom of the Syringe, and let the Air be pump'd out of the Receiver. If then you pull up the Piston, the Water will not rise. 2201.

2202. The Force, by which the Air presses upon Bodies, often breaks them, when the Pressure is not equal every Way.

EXPERIMENT 12.

2203. The Brass Cylinder, or truncated Cone, A, is cover'd with a flat Piece of Glass, and the Ingress of the Air is hinder'd by putting Wax round it; if the Air is pump'd out of the Cylinder, the Plate of Glass will be broken by the Pressure of the external Air, and reduc'd into a kind of Powder, if it be not too thin; if it be too thick it sustains the Pressure without breaking.

- Pl.68.F.2. 2204. Though the Air presses downwards, yet sometimes some Parts of the Glass are thrown side-wise with great Force, so as to endanger the Eyes of those that stand by; therefore we cover the Cylinder A with the Receiver R. And that the smaller Pieces of Glass may be taken away, and that no Piece may get into the Pump, I cover the Plate G of the Pump with Paper. The Paper has a Hole in it in the Place, that answers to the Hole, through which the Air goes out; so that the Paper does not hinder the Brass solid Piece B, whose Screw D answers to the Screw in the said Hole, from being join'd to the Plate G. To the same Solid, by Means of the Screw C, is join'd the smaller Brass Plate O, of the same Kind as those that cover the Glasses, as in Fig. 4. of this Plate. The solid Piece B has a Hole in it, and into the upper Part of the Hole is put the small Pipe E, which is bent at *i*. With a Leather, prepar'd, as was said of the Rings *, we cover the Plate O, and put the Cylinder A upon it; so that this Plate receives no Damage at all.

- * 2156. 2205. If the Glass sustains the whole Weight of the Atmosphere, you must give it a gentle Blow; for this Reason we make Use of a Receiver open at Top, as R.

EXPERIMENT 13.

2206. Take a Syringe A of the Diameter of three Quarters of an Inch; Pl.68.F.3. push down the Piston to the Bottom of it, and stop the Hole at the Bottom of the Syringe; if the Weights P, *p*, which together are equal to five Pounds, be join'd to the Syringe, and the Handle B of the Piston be held in the Hand, the Syringe will not descend, although it be sustain'd itself, together with the Weights; for it cannot descend, unless the Weight hung on it overcomes the Pressure of the Air, which exceeds six Pounds. If instead of five we hang on six Pounds, the Syringe will descend; because to the six Pounds there is superadded the Weight of the Syringe. Care must be taken that the Friction of the Syringe be very small.

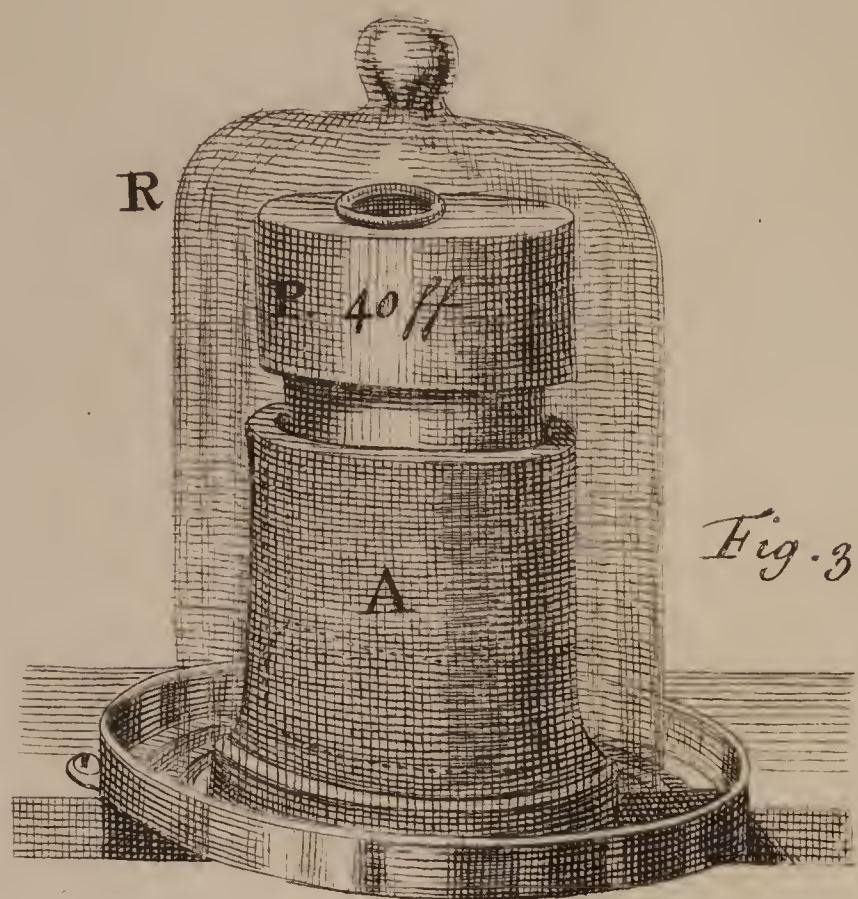


Fig. 3.

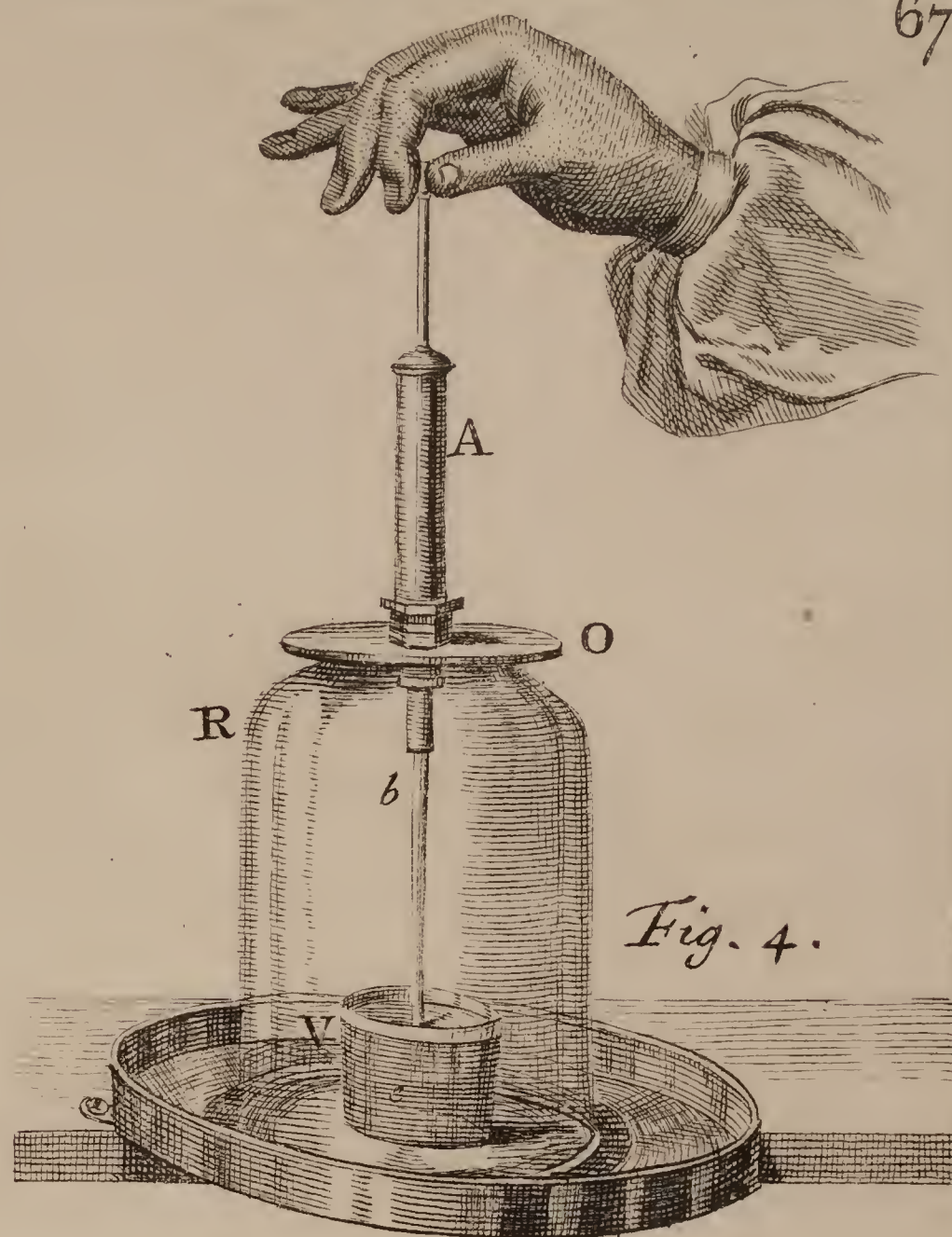


Fig. 4.

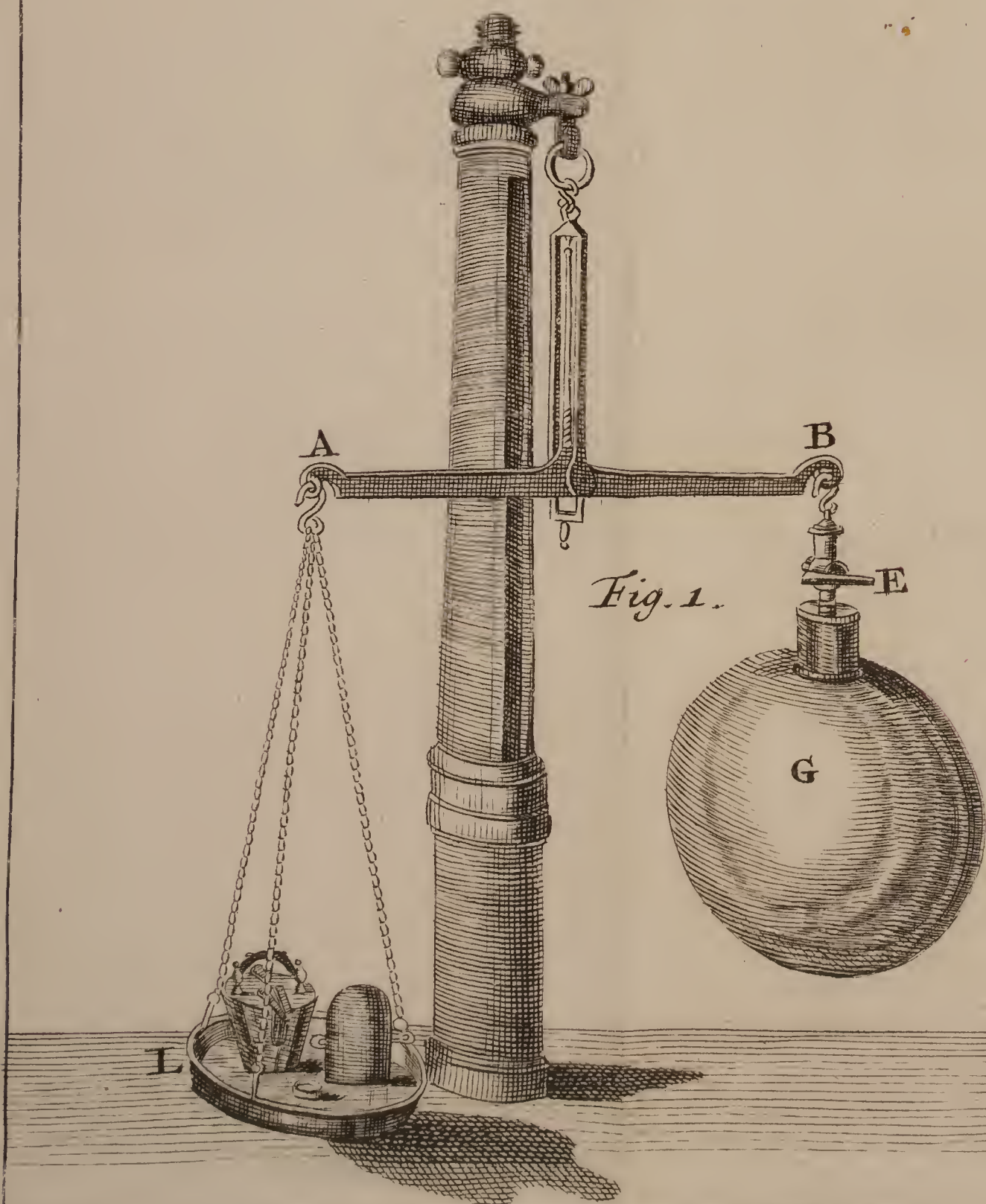


Fig. 1.

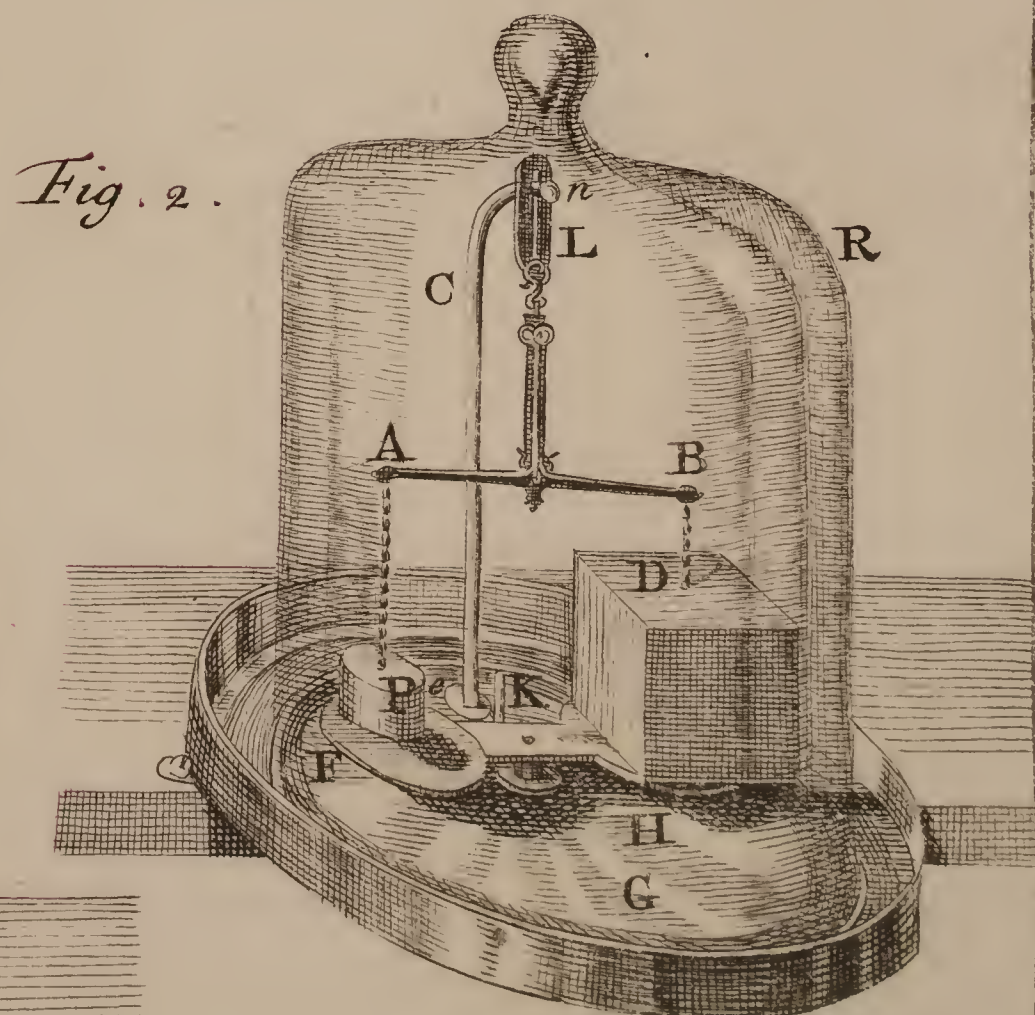


Fig. 2.

EXPERIMENT 14.

The Syringe descends by it's own Weight, in a Vacuum.

2207.
Pl.68.F.4.

EXPERIMENT 15.

We see a more sensible Effect of the Pressure of the Air, when the two Segments of a Sphere, H and E, are join'd together. Let the Brim or Edge of each of them be well polish'd, so that they may fit together, and, when they are applied close, put a little Wax between, to exclude the Air. There is a Cock in the Segment H, by which the two Segments, when joined together, may be applied to the Air-pump *, and which must be shut, when you have exhausted the Air. The Segments are suspended by the Ring A, and, by the Ring Q, you may hang to them the Weights that are laid upon the great wooden Scale T. If the Diameter of the Segments be three Inches and an half, a Weight of about 140 Pounds will be requir'd to pull them asunder. 2208. Pl.69.F.2.

We make Use of the Machine with three Legs beforemention'd *, and apply the Ring A to the Hook V, which can be rais'd and let down, that the Scale T may be suspended at a small Distance from the Ground. The Ring Q is put into the Hook G, which coheres with V by a small String, that the Segment E may not fall down, and receive Damage. 2209. 1441.

The Scale T together with its Chains weighs fifteen Pounds, we put on an hundred and twenty five Pounds, and the Segments are separated, if the Height of the Barometer be less than twenty nine Inches; some Weight must be added, when the Pressure of the Atmosphere is greater. 2210.

If these Segments are hung up in a Vacuum, they will be separated by so small a Force, as is requir'd to overcome the Cohesion of the Wax. 2211.

EXPERIMENT 16.

On the Plate G, of the Air-pump, is put the Wooden Ring BB, which is supported by three Feet; the brass, bent Plate D stands upon it, which makes a kind of Handle, and is fasten'd by Screws, one of which is seen at i. In the upper Part of the Handle there is fasten'd the Hook V, on which are hung the Segments H and E, join'd together, and exhausted, as in the last Experiment. 2212. Pl.69.F.3.

Then a Collar of Leathers is join'd, at Bottom, to the Plate G *. The Brass Wire F C passes through it; whose End C with the Ring * 2213. 2155.

of the Segment E is join'd to a Hook made of a small Brafs Wire, as is represented at N, in Figure 4.

2214. All these Things are inclos'd in the Receiver R, and the Air is exhausted ; and the Segments are very easily separated, by pulling the Handle M downwards.

The Ring B B hinders the lower Segment, when it falls, from breaking the Glafs R, or damaging the Plate G.

2215. A Force, equal to that, which was applied in the last Experiment but one, is requir'd to separate the Segments mentioned, when they are inclos'd in a Vessel, and Air being left between the Segments of the same Tenor as the external Air, and the Cock being shut, the Air in the Vessel is brought to a double Density.

A M A C H I N E,

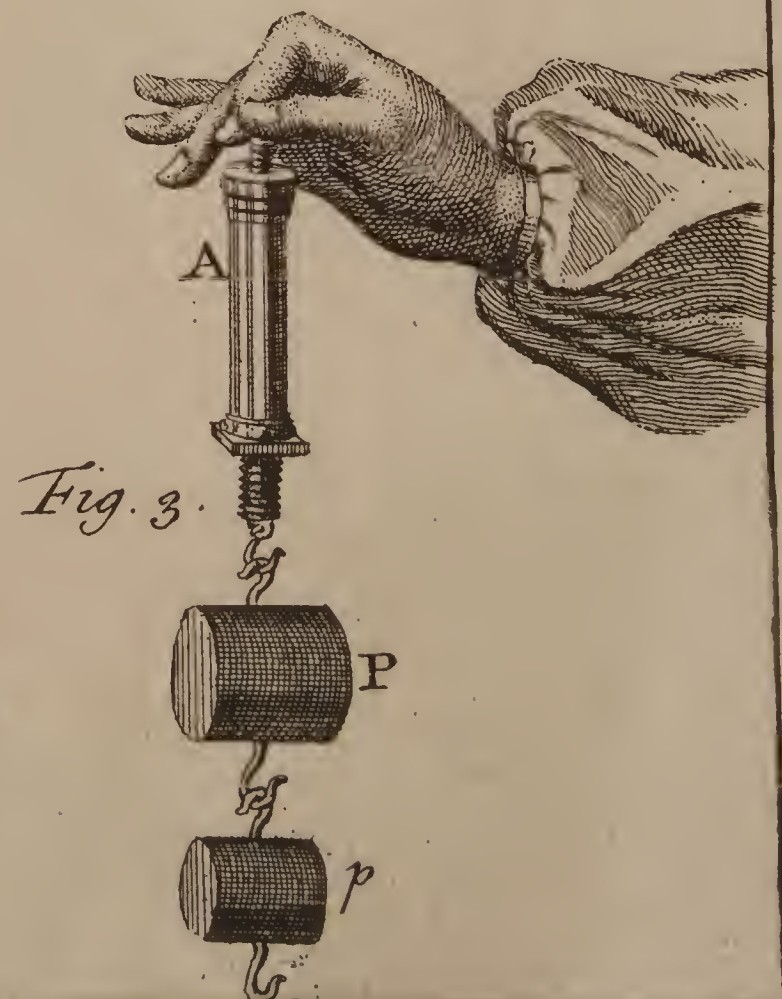
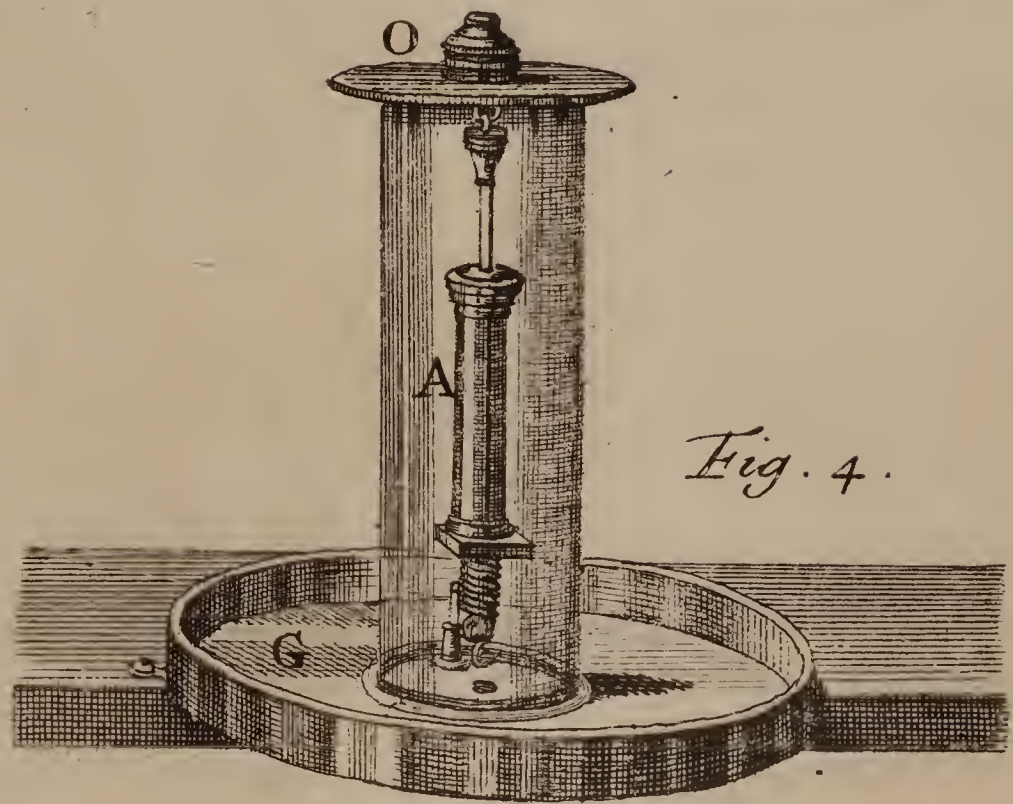
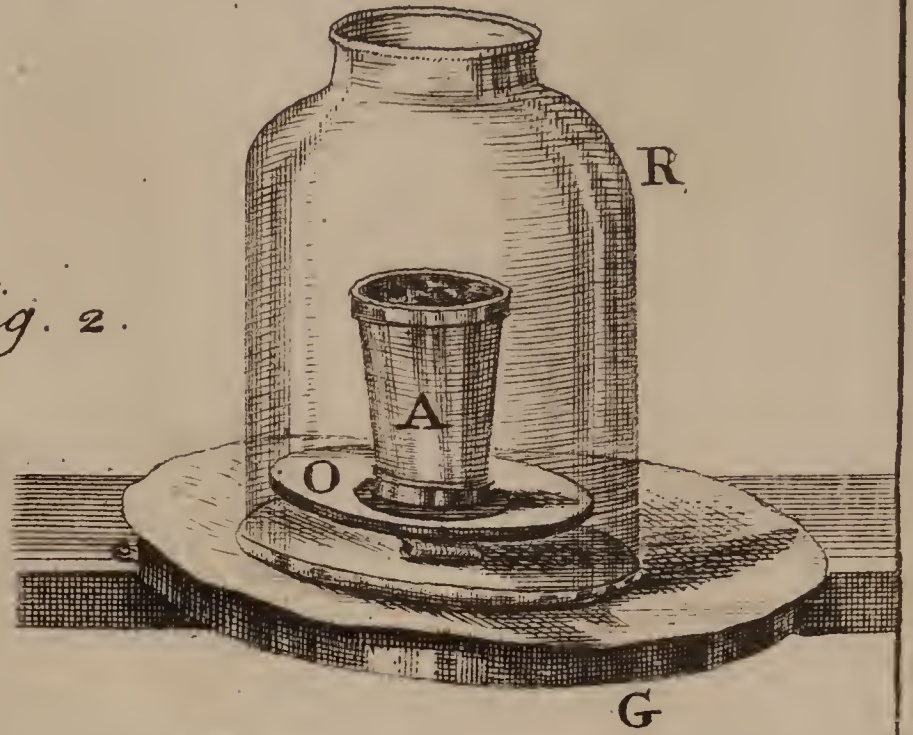
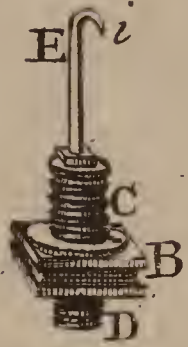
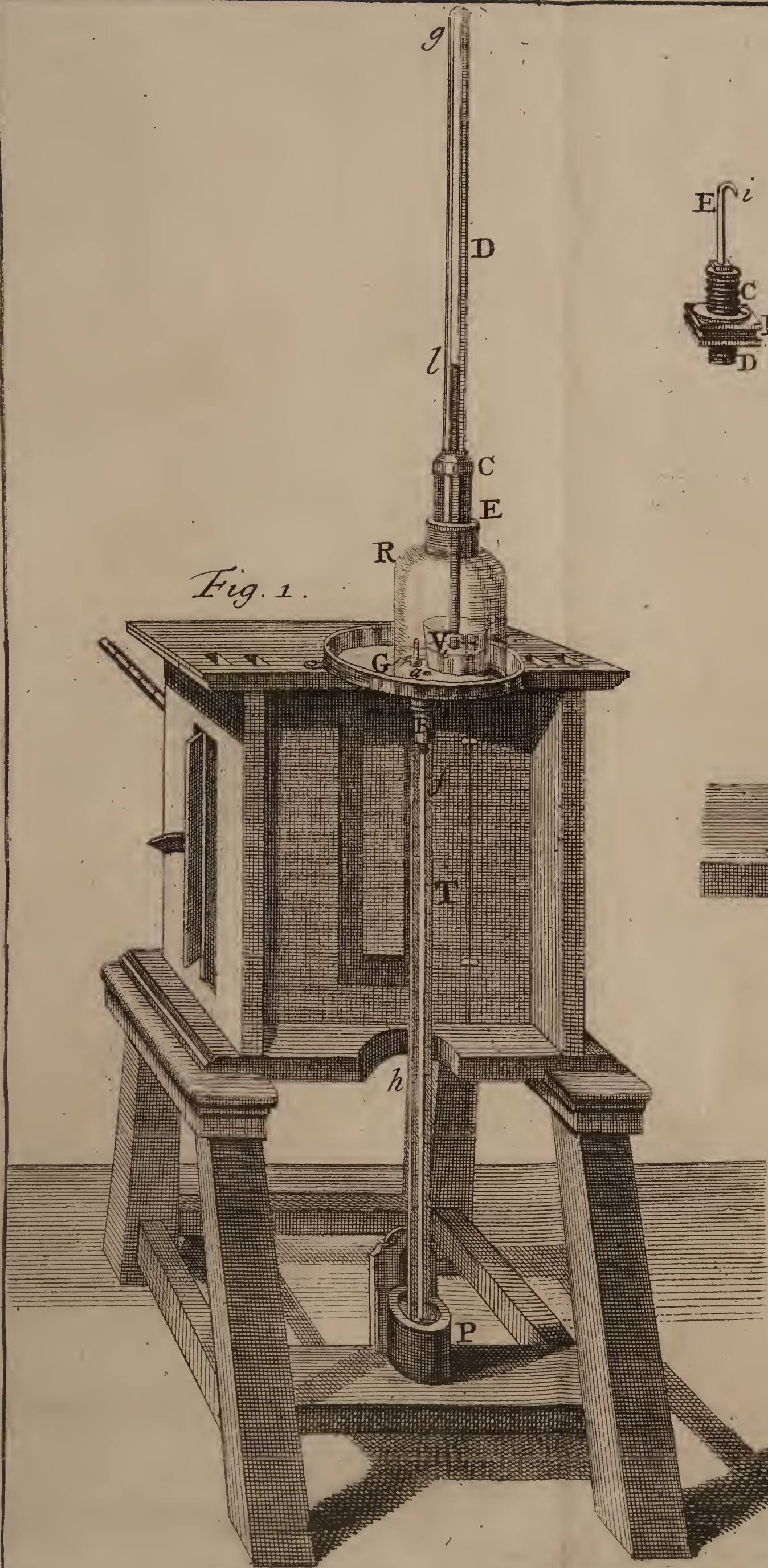
Whereby Experiments are made in condens'd Air.

2216. This Machine is of Brafs, and consists of the Hollow Cylinder Pl 70.F.1. MN, whose Diameter is six Inches, and Height eight, or ten Inches. It's Bases are made of thick Metal ; to these are join'd the Rings *b* and *d*, which surround the Cylinder, that the Machine may the better resist the inward Pressure ; for the same Reason the Ring *c* is also solder'd to the Middle of it, with which in the upper Part the Cock B coheres, and at Bottom the perforated Piece (*s* Fig. 4.), that by Means of a Screw the Collar of Leathers may be join'd to the Machine *. When we don't use the Collar of Leathers, we close the Hole with a plain Stop.

2217. The fore-part of it, which is represented separately at C, has a Pl. 70.F.2. Hole, whose Diameter is four Inches. This Hole is surrounded by the Prominence *o o*, and at a small Distance from it the four Screws *i, i, i, i*, go into the Base.

2218. This Hole is clos'd by a Cover, whose Inside is represented at D ; and it's Outside is seen at Fig. 1.

To the Inside of this Cover, which has a Hole in it, the Glafs Plane X is applied, whose Diameter is three Inches and an half, and which is more than a third of an Inch thick. The Diameter of the Hole, stop'd by this Glafs, is less than three Inches. The Cover is made hollow, to receive the Glafs ; but by Reason of the Thickness of the Glafs, the Metal must be pretty thick round it, and the Glafs is encompass'd with a Kind of Ring, that it may be fasten'd with Cement.



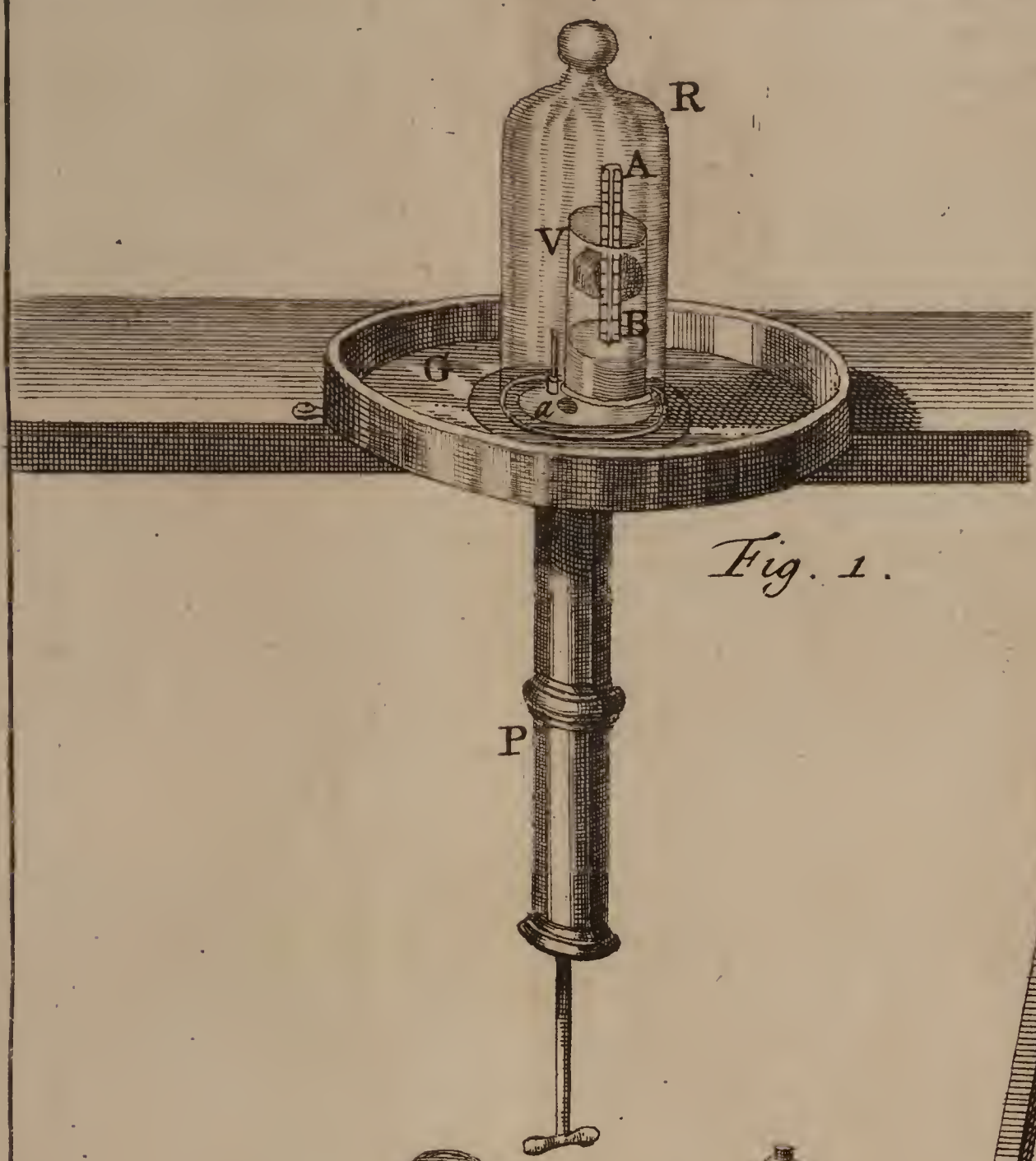


Fig. 1.

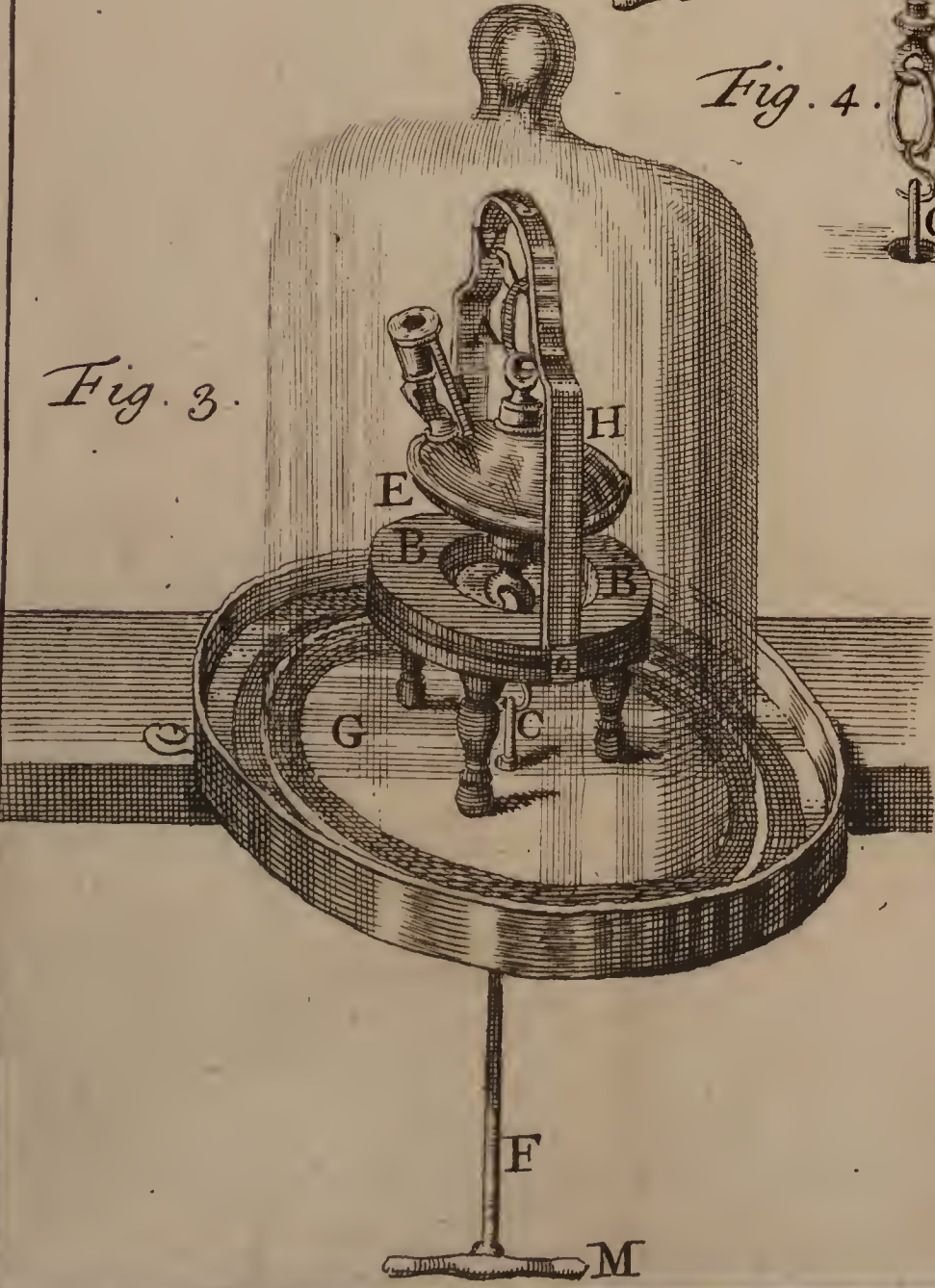


Fig. 3.

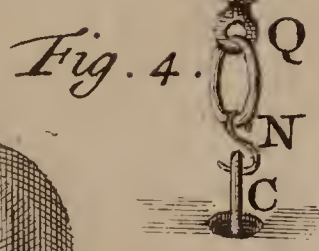


Fig. 4.

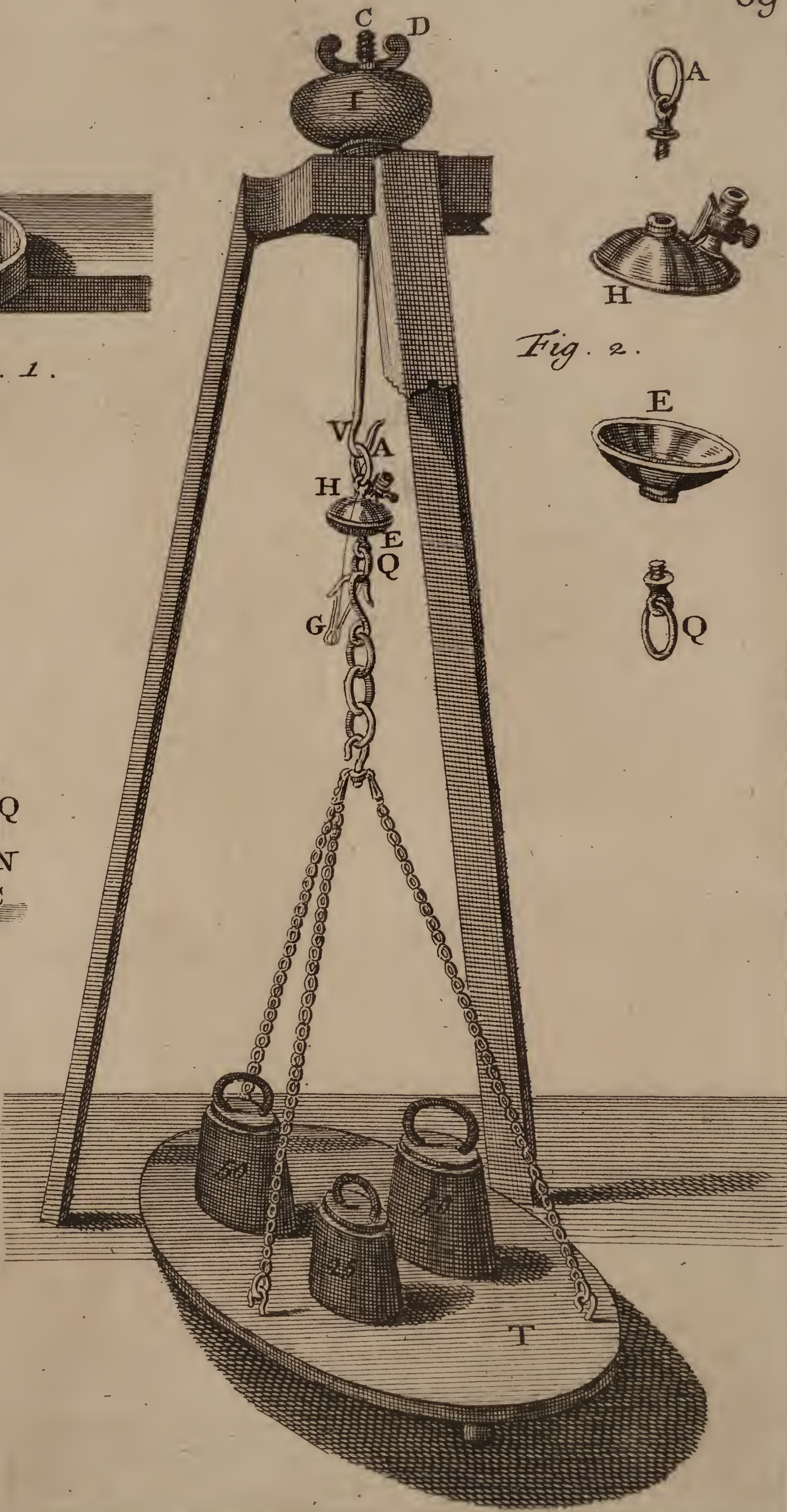


Fig. 2.



In the opposite Base, there is a like Hole, which is clos'd in the Inside, in the same Manner, by a like Glass Plane.

The Hole C is clos'd by the Cover D, as was said, which that it may be done exactly, the Ring, surrounding the Glass, is encompass'd with the Groove *nn*. Into this Groove is put a Ring of Leather, which covers the Bottom of the Groove, and is of the same Breadth. The same Thing must be observ'd with respect to this Leather, as was upon another Occasion *. 2219. * 1436.

When the Cover is applied to the Hole C, the four Screws *i, i, i, i*, go through as many Holes in the Cover itself, and the Ring *oo* goes into the Groove *nn*, and compresses the Leather in the Bottom of it; the external Screws (*e, e, e, e*, Fig. 1.) are join'd to the Screws *i, i, i, i*, and the Cover, by Means of them, is well fasten'd on; but the Ring *oo* stands out in such Manner, that it alone immediately touches the Cover; so that the Leather sustains the whole Compression.

This Machine is join'd to the wooden Stand FF, which is put upon another Stand G also, from which it is easily remov'd. 2220. Pl.70.F.1.

When the Air is to be compress'd, we make use of the Syringe A, from which the Bottom B may be separated. The Piston E fills it's Cavity exactly; the Leathers *ii*, are so dispos'd, that the Piston must be thrust in through the Hole *p*, the Bottom being taken away; the same must be observ'd of these Leathers as was said above *. Whilst the Piston is thrust in, it's Tail D is put through the Hole in the Cover C, which is applied to the Syringe; that this may be done the Handle M is separated from it, which is again join'd to it, and retain'd by the Screw *n*. 2221. Pl.71.F.1. * 2141.

After the Piston is thrust in the Bottom B is added to the Syringe, and a Leather Ring * being put between, it is well fasten'd by the help of Keys, one of which is join'd to the Cover, and the other to the Syringe itself at *f*. * 1438.

At *t* there is applied a small Leather Valve, that the Air may go out of the Syringe, through the Hole in it's Bottom, but not get into it: For this Reason, when the Piston is remov'd from the Bottom, the Syringe remains empty, 'till the Piston comes to the Top; but then the Air enters through the Hole *o*. When a Syringe is us'd, whose Bottom can't be taken off, there is a peculiar Method of thrusting in the Piston; I generally prefer the Syringes whose Bottoms may be remov'd, excepting such as are us'd in Air-Pumps. 2222.

The Syringe is join'd to the Cock B, of the Cylinder MN, the mercurial Gage K being put between. This consists of a Glass Tube of 2223. Pl.70.F.1.

of a very small Bore, and contains a small Quantity of Mercury, which Compresses the Air in the hinder Part of the Tube, as much as that, in the Machine itself, is compress'd. But the Degree of Compression in this Tube is easily measur'd.

2224. The Machine is now to be taken from it's Stand G, the Cock B being open'd. The Person, who undertakes to compress the Air, sets his Feet upon the Boards F, F; and raises, and depresses the Piston, and, by continuing this Motion, compresses the Air in the Vessel as much as he pleases; then the Cock B is shut. The Experiment being ended the Air must be let out through the Cock, before the Screws, which keep on the Cover, are loosen'd.

EXPERIMENT 17.

2225. Join together the Segments H and E*; and suspend them in the
Pl. 70. Cylinder MN, by help of the solid Piece P, which is fixed in the
F. 3. 4. upper Part of the Cylinder, by help of the Screw *p*, which goes
* 2208. into the lower Part of the Cock B; this Piece has a Hole in it, that the Air may go through the Cock, into the Cylinder.

- * 2216. The Collar of Leathers I is join'd at *s* to the Machine*. The Brass Wire, which goes through this Collar, must be thicker, than in the other Experiments.

To the End of this Wire, which goes into the Cylinder, is join'd the Piece R, into which this End, which has a Screw, is put. This Piece is easily join'd to the Segment H, as the Figure shews.

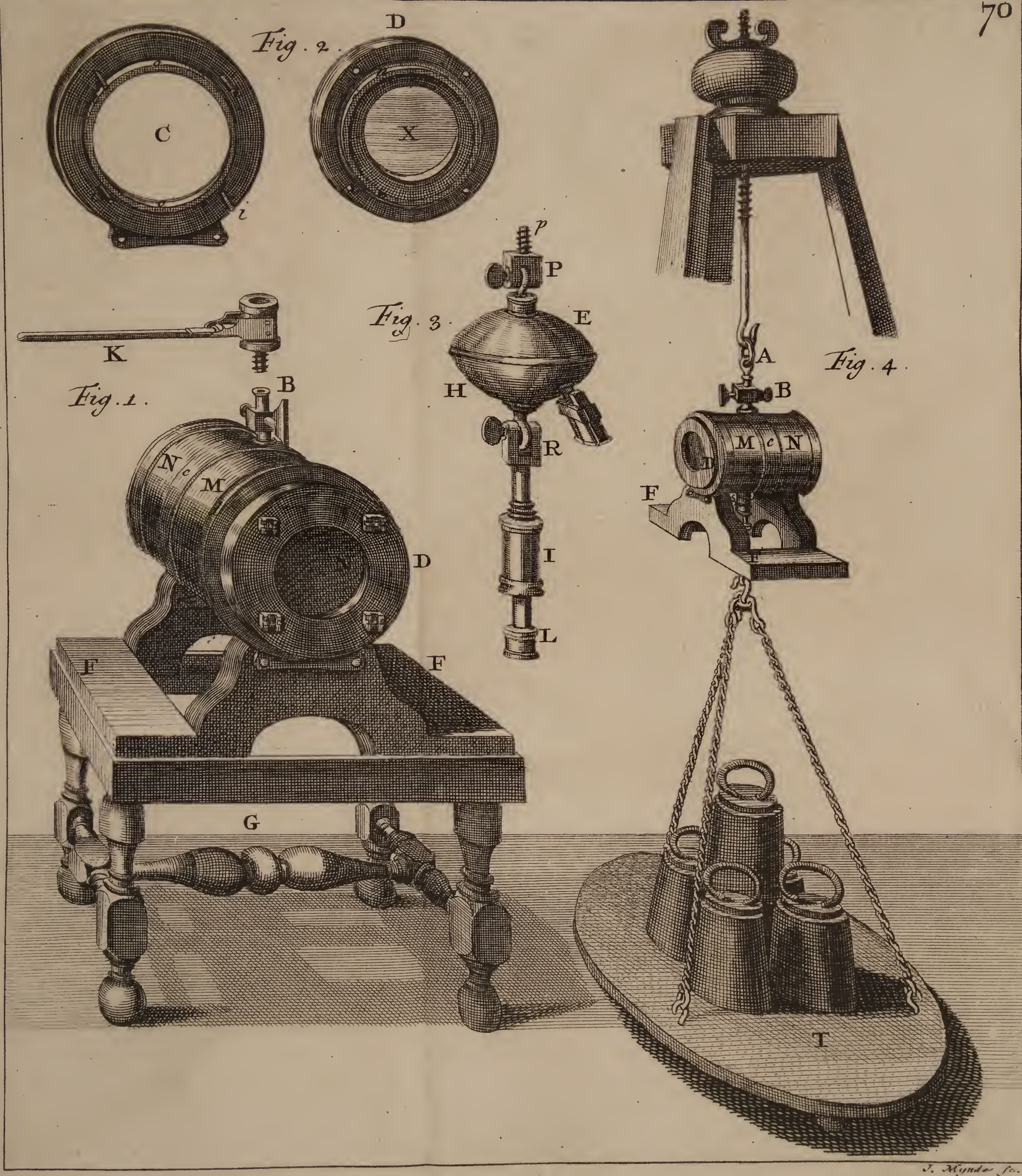
The Cock of the Segment H is shut, that the Air may not get between the Segments; for which Reason Wax is put round it, as in the foregoing Experiments.

2226. Things being thus dispos'd, the Cover is applied to the Cylinder*,
Pl. 70. F. 4. and the Air is compress'd. The Syringe with it's Gage is remov'd †,
* 2219. and, the Ring A being join'd to the Cock B, the Machine is sus-
† 2223. pended by the Hook V, as was said of the Segments above*.

- * 2209. To the lower End L (*Fig. 3.*) of the Wire that goes through the Collar of Leathers, there is join'd a Ring also, on which the Scale T is suspended.

By putting Weights upon this Scale, the Segments in the Cylinder are separated. If the Density of the Air in the Cylinder be double, the Weight will not differ much from that, which was us'd in the last Experiment but one; the Weight must have been doubled, if the Density of the Air had been triple, or if the Segments had been exhausted.

But





But Care must be taken, 1. That the Screw DC be so dispos'd, that the Scale T may descend but a little before it be put upon the Ground; otherwise the solid R (*Fig. 3.*) would run against the inner Surface of the Cylinder with too great a Force. 2. That two Sponges are plac'd, so as to receive the Segment H, that it may not be damag'd.

2227.

EXPERIMENT 18.

Apply the Pipe AB to the Plate G of the Air-pump, which Pipe has a Cock at it's lower End, and to which is join'd, at Top, the smaller Pipe C, which rises above the Plate. The Pipe D is applied to the Hole through which the Air is taken out. The Glass Receiver S is put upon the Plate G, in such Manner, that the Pipe C may answer to the Middle of it. Upon the Receiver S is put the Receiver R, that we may have an Height of about three Feet. The End A, of the Pipe AB, is immerg'd in Water, contain'd in the Vessel V, and the Receivers R and S being exhausted, the Cock is open'd; the Water will spout up into the Receiver with a great Force; namely by that Pressure, with which it can be sustain'd in a Pipe that has no Air in it, at the Height of thirty two Feet *.

2228.
Pl. 71.F.2.

* 1089.

EXPERIMENT 19.

The Air's Elasticity produces the same Effect. Let there be a Brafs Cylinder V, exactly clos'd. There must be a Hole in the Bottom to pour in Water, which afterwards you shut up with a Screw. To the upper Part of the Vessel there is solder'd a Pipe, which goes down almost to the Bottom; and to the other End of it, that stands above the Vessel, the Cock E is join'd. By help of a Screw this Vessel is fitted to the lower Side of the Plate G of the Air-pump; there is also here a prominent Pipe C, which is cover'd with the Receivers, as in the foregoing Experiment. If the Air be exhausted from them, and the Vessel V is about two Thirds full of Water, when you open the Cock, the Water will violently spout up into the Receivers, by the Force of the Spring of the Air contain'd in the upper Part of the Vessel V. Here the Air presses upon the Surface of the Water; when you open the Cock, the Pressure in the Pipe becomes less, therefore the Water must go into the Pipe.

2229.
Pl. 71.F.3.

EXPERIMENT 20.

Even in the open Air, the Water will violently spout out of the Vessel V, if, having pour'd in Water, as in the 17th Experiment, the Air be forc'd into the Vessel, by the Syringe above-mention'd *.

2230.
Pl. 71.F.4.
* 2221.

EXPE-

EXPERIMENT 21.

2231. If a Glas inverted be immerg'd in Water, the Air keeps out the Water, at whatever Depth it be immerg'd; yet the deeper the Glas is put down, the less Space the Air is reduc'd into.

2232. Upon this Principle are made the Machines in which Divers go down into the Sea. They are made like Bells, and descend by their own Gravity; the Water does not rise up to the Diver in the Bell; fresh Air is sent down continually by the Bladders tied to a Rope, which he draws down to him; the Air, heated by his Respiration, rises to the upper Part of the Bell, and is there driven out through a Cock, by the Pressure of the Water, that pushes up, and compresses the Air in the lower Part of the Bell; which Pressure overcomes the Force with which the Water endeavours to descend through the Cock; for the Pressure of Fluids is encreas'd in

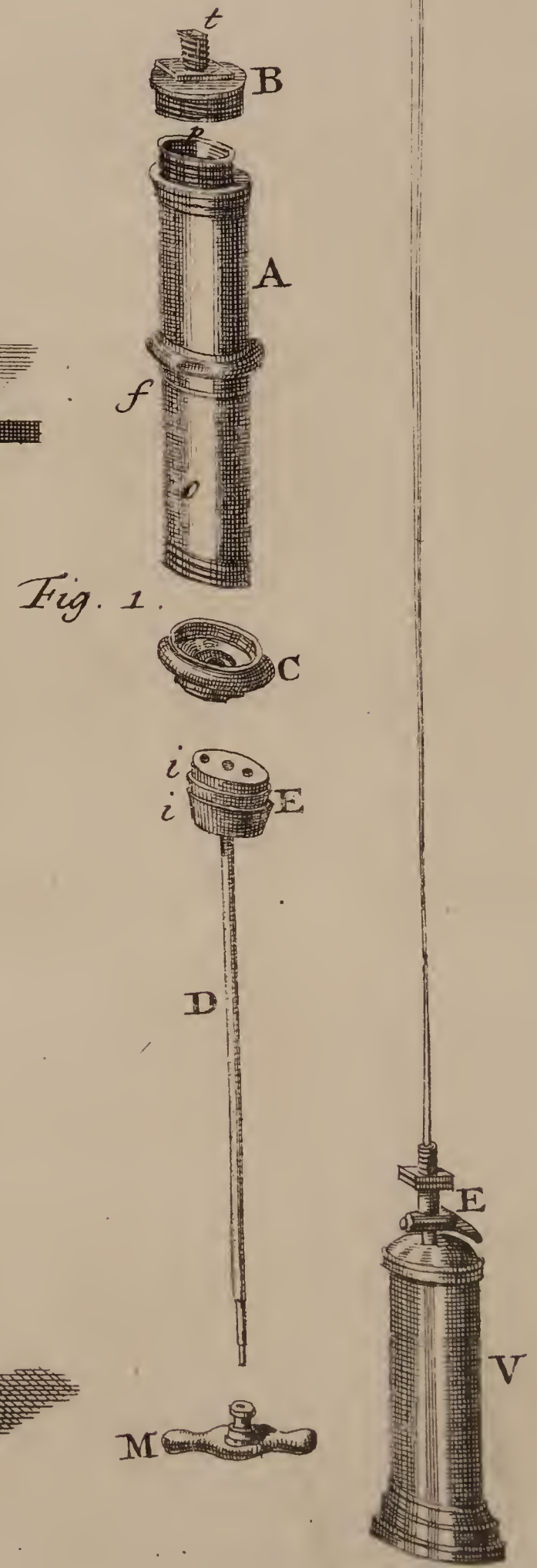
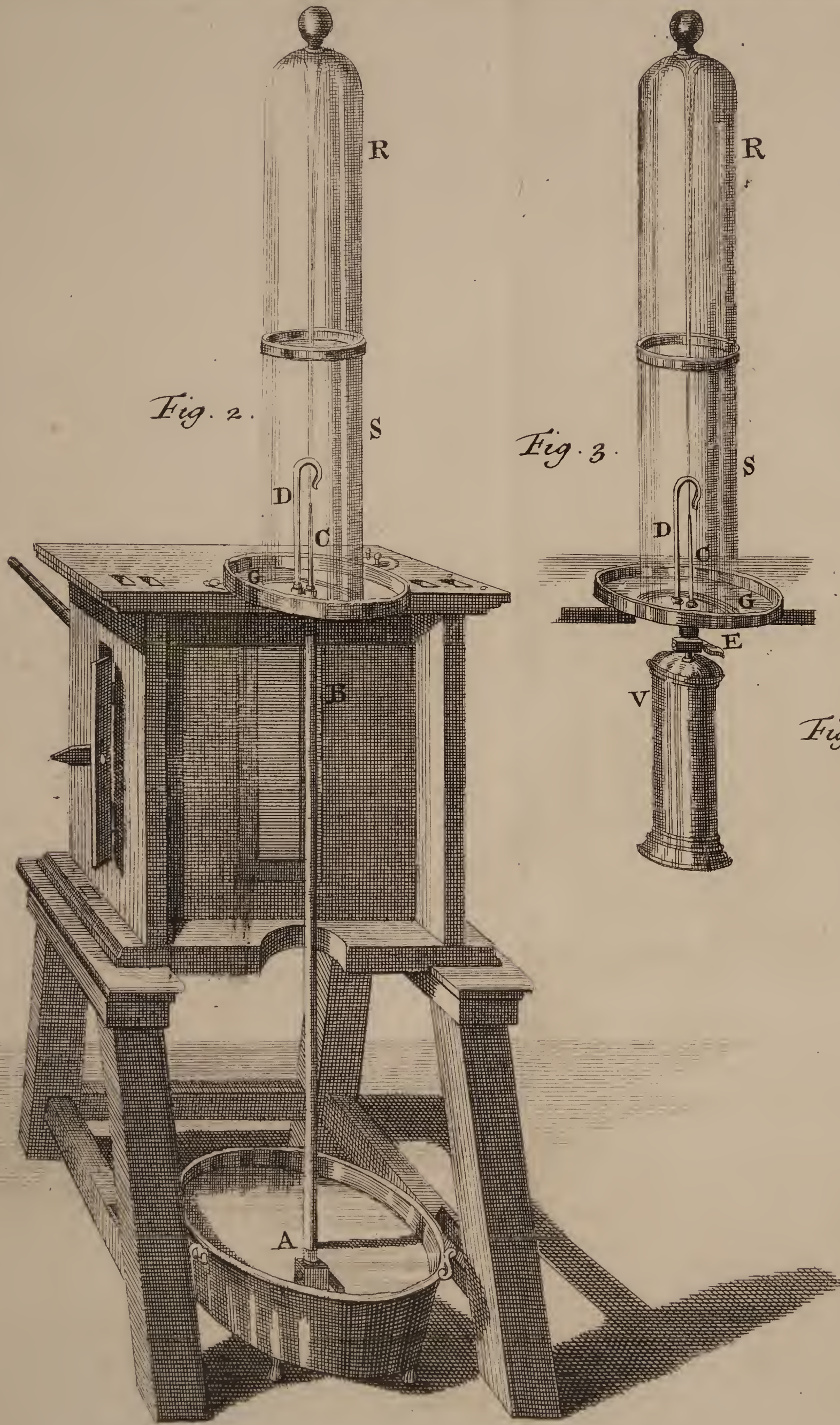
* 1468. Proportion to their Depths *.

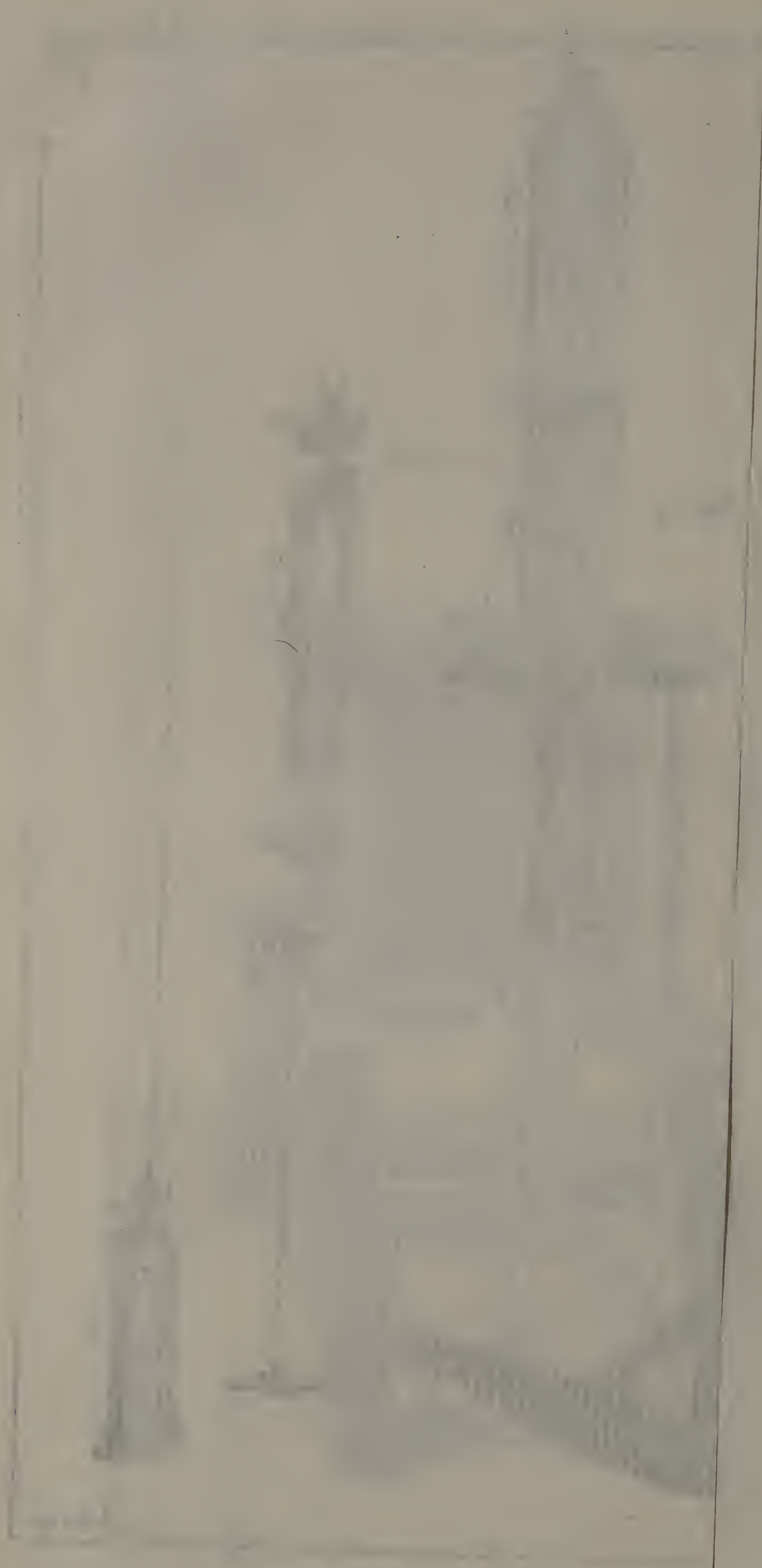
EXPERIMENT 22.

2233. Take little Figures of Glas that are made hollow, of an Inch and Pl 72.F.1. half long, representing Men; these little Images have a small Hole in one of their Feet, and are lighter than Water. Immerse them into the Water contain'd in the Glas AB. This Glas is about a Foot, or 15 Inches high. This is put upon the Plate G of the Air-pump, and cover'd with the Receiver R. A Part of the Air being exhausted, it goes out of the little Images also, whose Place is immediately taken up by the Water, when the Air is let into the Receiver again; the Images are now heavier, and go to the Bottom. Some of the Air being again exhausted, the Pressure upon the Surface of the Water is diminished, and the Air in the Images expands itself, and drives out the Water, and the Images rise up again, and have several Motions, when the Pump is mov'd.

EXPERIMENT 23.

2234. We may make Use of this Glas Vessel with the Figures in it, in another Manner, without the Air-pump. It is fill'd with Water, and cover'd with a Bladder, which is tied fast to the upper Part of the Vessel. If the Bladder be press'd with the Finger, the Surface of the Water is compress'd more; and this, being more compress'd, enters into the Images through the Holes in their Feet, and compresses the Air more in them. The Images being made heavier, go to the Bottom of the Vessel, faster or slower according to the Bigness





Bigness of the Hole, and also according as the specific Gravity of the Images comes nearer to the specific Gravity of the Water. Taking away your Finger, the Air in the little Men, being less compress'd, expands itself, and drives out the Water, and the Images rise up again to the Surface of the Water, as in the last Experiment.

EXPERIMENT 24.

Animals cannot live without Air. If any Animal be included in the Receiver V, and the Air be drawn out, the Animal will immediately be in Convulsions, and will fall down dead, unless the Air be suddenly re-admitted. Some Animals will live in a Vacuum longer than others. The Bodies of the Animals are swoln, whilst, the external Pressure being taken away, the Air, or some elastic Fluid, expands itself in the Vessels. 2235.
Pl. 72.F.2.

EXPERIMENT 25.

Some Fishes also cannot live without Air; but in others you see no such Change, but the swelling of their Eyes. What Experiments you make upon Fishes, must be made in the Glass Receiver V, which is set upon the Plate of the Air-pump, and which contains the Water with the Fishes. This is covered with the Receiver R, and the Air is exchanged. The Pressure of the Air upon the Surface of the Water being taken away, the Air in the Body of the Fish expands itself, by which it becomes lighter, and cannot descend in the Water. 2236.
Pl. 72.F.3.

EXPERIMENT 26.

Experiments are made upon Animals in compress'd Air, by Help of the Machine above-describ'd *. In that Case Animals do not soon die; because the Vessels in the Body are not broken, by compressing the Air; the Animals become rather brisker. Yet if they continue long in that condensed Air, it is hurtful to them; and in a greater Compression, they will die in a little Time. 2237.
2216.

EXPERIMENT 27.

We may see what happens to the Vessels of an Animal, in compressed Air, if we suspend a Bladder blown up, and well clos'd, in the said Machine *. When the Air is compress'd, it becomes flaccid; but, when the Cock is opened, it suddenly expands itself. 2238.
2216.

EXPERIMENT 28.

2239. From several Fluids, when they are put under a Glafs Receiver, and the Air is exhausted, an elastic Fluid is separated. In this Case we always observe an Ebullition of the Fluid, which is often very violent.

2240. In the eighth Chapter of the first Book, I mentioned an Experiment concerning Bodies falling in a Vacuum *, I shall now explain it.

A MACHINE,

Whereby two Bodies are let down in Vacuo, at the same Time.

2241. This Machine is joined to the Cover of the Receiver. The upper Surface of this Cover is seen at Fig. 1. the lower Surface at Fig. 2. The Machine itself, is represented separate from the Cover, in the other Figures.

2242. The Brass Plate A is hexagonal, the Angles being cut off, and it is perforated in several Places, to make it lighter. The Axis *ae* is perpendicular to it, behind it, whose Part *ab* is cylindrical, and the Part *be* square, but the End *e* makes a Screw, which the Nut *c* fits.

2243. To the same Plate, which is represented at B, at the fore Part of it, are applied six small Brass Plates E, E, E, E, E, E; which are bent, and elastic. One of these Springs is represented separately at CD; towards C there are two small Holes, through which the Screws *n, n* go, that the Spring may be fastened in it's Place. The End D agrees to a Side of the Hexagon, and presses the Plate B by it's Elasticity.

2244. The Spring CD is perforated at *oo*; and through this Incision passes the small Plate *i*, which coheres with the Plate B, and turns upon a Center. Every Spring has such a small Plate, which is seen more distinctly in Fig. 5. A B represents a Section through the Center of the hexagonal Plate, in such a Position, that this Section, which we suppose vertical, passes through the Incisions of the two Springs E and E. The Plates, of which we are speaking, are represented at *i, i*; a Piece *p* passes through each of them, which is prominent on both Sides.

2245. The Plate of the lower Spring acquires an horizontal Position by it's Gravity; because the Piece *p* is sustained by the Spring itself. If, when the Plate is in this Position, it be pressed downwards,

wards, the End D of the Spring is separated from the Plate A B by the Action of this Piece.

Upon the square Part of the Axis above-mentioned of the Plate A B *, is put the small Wheel R, which has Teeth, and which is represented sideways at *r*; the Teeth of it are oblique, that they may answer to the Screw which we shall speak of presently. We have a Section of this little Wheel, joined to the Axis, and fastened by the Screw *ec*, at *r*. 2246. 2242.

That this Machine may be fastened to the Cover, there is a Cylinder H N, which is joined to the Bottom of it, and which ends in the spherical Head I, two Segments at opposite Parts being cut off; this Head is perforated at *s*; through which Aperture is put the Axis *ab* (Fig. 3, 5.) before the Wheel *r* is joined to it, and fastened. 2247. Fig. 2.

To the same Cylinder H I, is added the Screw G, which is retained between the Plates L and M; the Part *g* passes through the Hole *f*, and *hl* through the Hole *d*. The Spiral of this Screw agrees to the Teeth of the Wheel, so that, by turning the Screw about it's Axis, the Wheel is mov'd, and the Plate A B (Fig. 5.) with what is joined to it is turned round. 2248.

The small Pipe X goes through the Cover, and is solder'd to it, to which the Screw G so answers, when it is fix'd in it's Place, that it's Axis, if it be conceived to be continued, coincides with the Axis of the Pipe.

The Part P of the Key F P fills this Pipe, and indeed so exactly, that the Air cannot pass by, whilst the Key is turned round, which shou'd be anointed well with Oil and Wax. 2249.

This has a Roller in it's lower Part at *m*, which Hole is square, into which goes the Part *l* of the Screw, which is also square, and fits the Cavity.

All the Parts are represented join'd together in Fig. 1. besides those, which we have hitherto explained, there is a Collar of Leathers *, which is put upon the Cover, and solder'd to it, through which the Brafs Wire S T passes, to whose End is joined the Plate V at right Angles to it. 2250. Fig. 1. 2155.

To know where this Collar of Leathers must be fix'd, turn the Key F till you bring the lower Side of the Hexagon A into an horizontal Position; then the small Plate *i*, which goes through the lower Spring E, will be horizontal also; the Plate V shou'd now answer to *i*, so that, by pushing down the Wire S T a little, the Spring may be separated from the Plate A, as was before explain'd *. 2245. 2251.

EXPERIMENT.

2252.
Pl. 72.F. 4. That this Experiment may be the more conveniently made, the Air-pump is taken off from it's Stand, and is laid upon the low Stand S S.

At the Sides of the Plate G, upon which the Glaffes, which are exhausted, are laid, are fastened two wooden Pillars A E, A E, the Feet of which go through the upper Board of the Air-pump, and are fastened by Wedges, as *t*.

The Pillars are above five Feet high; these are join'd by four Pieces of Wood, B B, C C, D D, E E. The Distance between G and B B is nine, or ten Inches; B C, C D, D E, are each equal to 18 Inches.

These Pieces of Wood are broader in the Middle, that there may be an Aperture, or round Hole in each, whose Diameter is equal to five Inches and an half.

* 2157. Four Glafs Cylinders F, F, F, F, are made use of; the inward Diameter of each is four Inches, and the Height a Foot and an half. The upper Hole of every one of them is encompass'd with a round Piece, with which coheres an horizontal Ring made of a Plate of the same Metal, that, when Leather is put between *, one Glafs may be set upon another. These four Cylinders are put one upon another, and make, as it were, one hollow Glafs Column, which passes through the Holes in the Pieces of Wood. This Column must be so plac'd, that it may go through the Middle of all the Holes, as near as possible; to effect which the Position of the whole Column must frequently be altered a little; for this Reason the lowest Cylinder is laid upon the Plate G, without putting a Leather between; but, after the Cylinders are fix'd, the Air is hinder'd from getting between the Plate and the Brim of the Cylinder, by putting Wax round it *. The Cylinders are fastened by Means of the little Wedges *x*, *x*, *x*, &c. made in such Manner, that they may suit the Glafs and the Hole.

* 2241.
* 2157. The Glafs Receiver R is laid upon the uppermost Cylinder; the Bottom of it is cylindrical, and this Part of it answers to the Cylinders mention'd. The Diameter of the Receiver in the Middle is about seven Inches; and the upper Hole is of five Inches Diameter. This Aperture is clos'd with the Cover above-mention'd *, Leather being put between *, and the Machine, there explain'd, is then inclos'd in the Receiver; but the Bodies, to be let down in Vacuo, must first be join'd to the Machine.

To

To do this, we put a Piece of Gold Coin *p* together with a small Feather *q* between a Spring, as E, and the Plate B; both which Bodies are retain'd by the Pressure of the Spring, if the Tail of the Feather is of the same Thickness as the Money; wherefore, that we may make use of a lighter Feather, we must choose a thin Piece of Money (for Example, a *Ducat.*) Each of the Springs shou'd retain Bodies like these, in the same Manner. 2253. Pl.73.F.4.

The Air is exhausted from all these Glasses, and by thrusting down the Brass Wire *st* a little, the lower Part of the lower Spring is separated from the Plate, to which all the Springs are applied *, and both the Bodies, which are held by the Spring, are let loose at the same Time; and they come to the Plate G exactly at the same Time also. 2254. Pl.72.F.4. * 2251.

The Experiment is easily repeated; the Key *f* is turned about, that another Spring may come to the lower Place *; and thus it may be repeated six Times. If during these Repetitions some Air be let in, a Difference in the Time of the Fall of the Bodies is perceiv'd, and the Difference is the greater, the more Air is let in. 2255. * 2248.

A Spectator will see the Bodies falling, if he be at such a Distance, as to perceive all the Glasses at one View, if he be at a less Distance, let him keep his Eyes on the Plate G.

A more simple Method of repeating the Experiment, may indeed be us'd; but I think this, which I have made use of, the best Method of letting loose the Bodies, at the same Time, that they may fall directly down, and separately. But the following Method is very simple, if the Bodies are to be let down only once. 2256.

The Receiver R in this Case is remov'd, the upper Cylinder also may have a smaller Aperture. 2257.

This upper Cylinder is clos'd with the Brass Top O, to this is join'd a Collar of Leathers A *, by Means of the Screw B, which goes through the Cover in such Manner, that the elastic, bent Plate D E is join'd to the Cover by Means of it, which Plate is perforated at Top, over which Aperture is folder'd the Ring C, into which the Screw B goes. Pl.73.F.6. * 2155.

The extreme Parts *rr* of the Plate, come together by Means of their Elasticity, the Ends being a little bent.

In this Plate is inclos'd the oval, Brass Plate F, whose smaller Diameter may be contained within the Plate D E, without separating the Ends of it.

Within the same Plate D E, the Brass Wire G I goes, which passes through the Collar of Leathers A, and therefore also through the

the Cover O. To the lower End I of which Wire G I the said Plate F is join'd, which may be mov'd by Means of the Handle Q, and turned round, whereby the Ends r, r , of the Plate DE are separated; because the longer Diameter of the oval H exceeds the Distance between the opposite Parts of the Plate, when it's Extremes r, r , are join'd by Means of the Elasticity; between these the Gold and Feather are put, when the Experiment is to be made.

C A H P. VI.

The Description of several Machines, whose Action depends upon the Air, and the Explanation of their Effects.

EXPERIMENT I.

2258. *Pl. 74. F. 1.* **L**ET one End a , of the Curve Tube $a S b$ be immersed in Water, whilst the other End b descends below the Surface of the Water. If by sucking, or any other Way, the Air be taken out of this Tube, the Water will run through b . This Instrument is called a *Syphon*.

2259. This Effect arises from the Pressure of the Air, which drives on the Water in the Syphon, by it's Pressure upon the Surface of the Water in the Vessel. The Air does also press against the Water that goes out of the Orifice b , and sustains it. These Pressures are equal, and act contrariwise in the upper Part of the Syphon, with a Force equal to the Weight of the Atmosphere, taking away the Weight of the Pillars of Water which are sustained by the Pressure. The Pillar of the Water in the Leg $S b$, is longer than the opposite Pillar of Water; therefore, the Pressure of the Air is more diminished on the Side $b S$, and the opposite Pressure overcoming it, the Water flows towards b .

EXPERIMENT 2.

2260. The Syphon above-mention'd has this Inconveniency, that, if once it ceaseth to work, the Water will not run again, unless the Air be drawn out of the Tube afresh. This may be corrected by making a Syphon in the Figure $d R e$, whose Legs are equal, and turn'd up again; for if the Syphon be fill'd with Water, and one Leg be immersed in it, so that the Surface of the Water may be

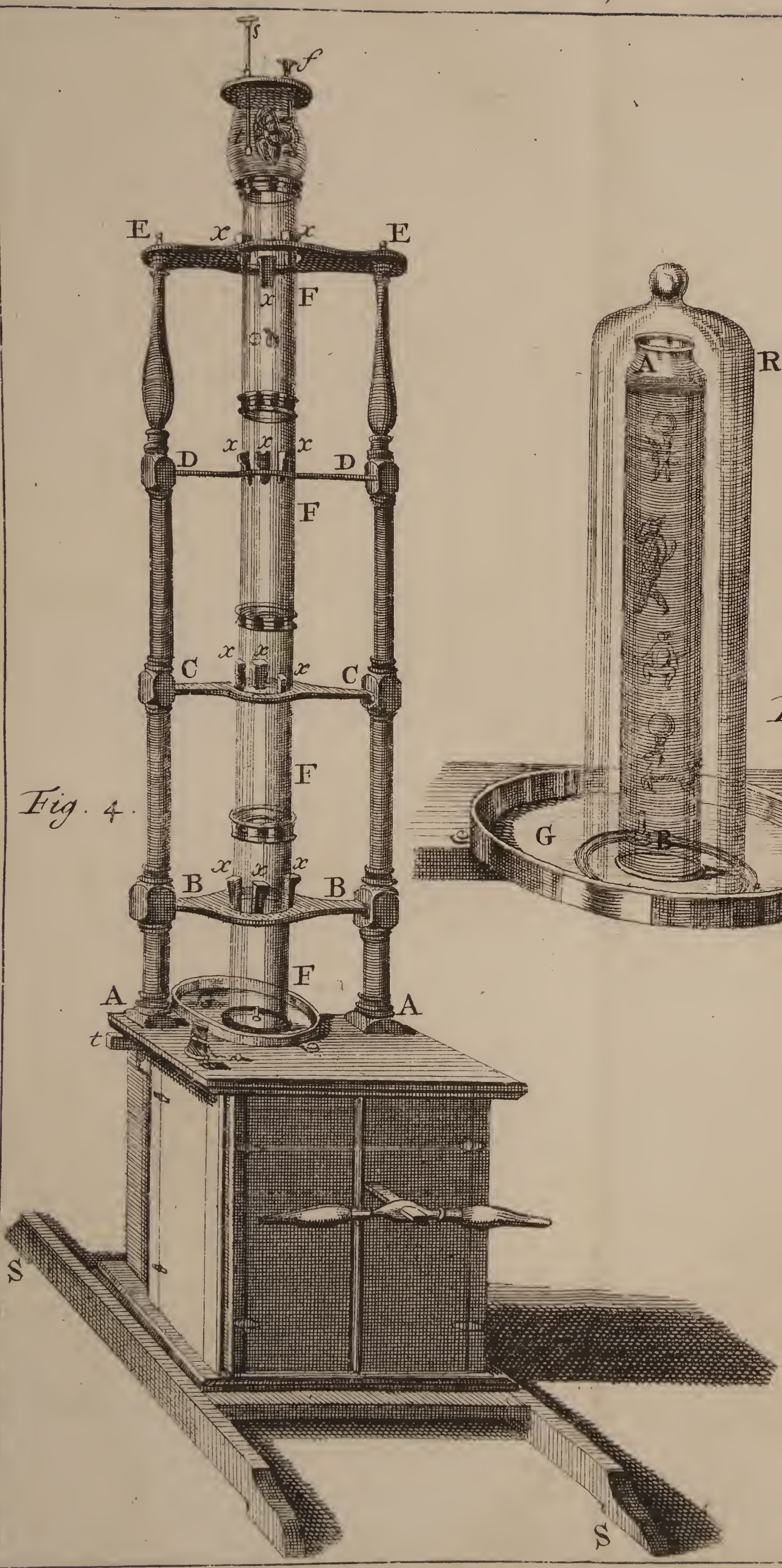


Fig. 4.

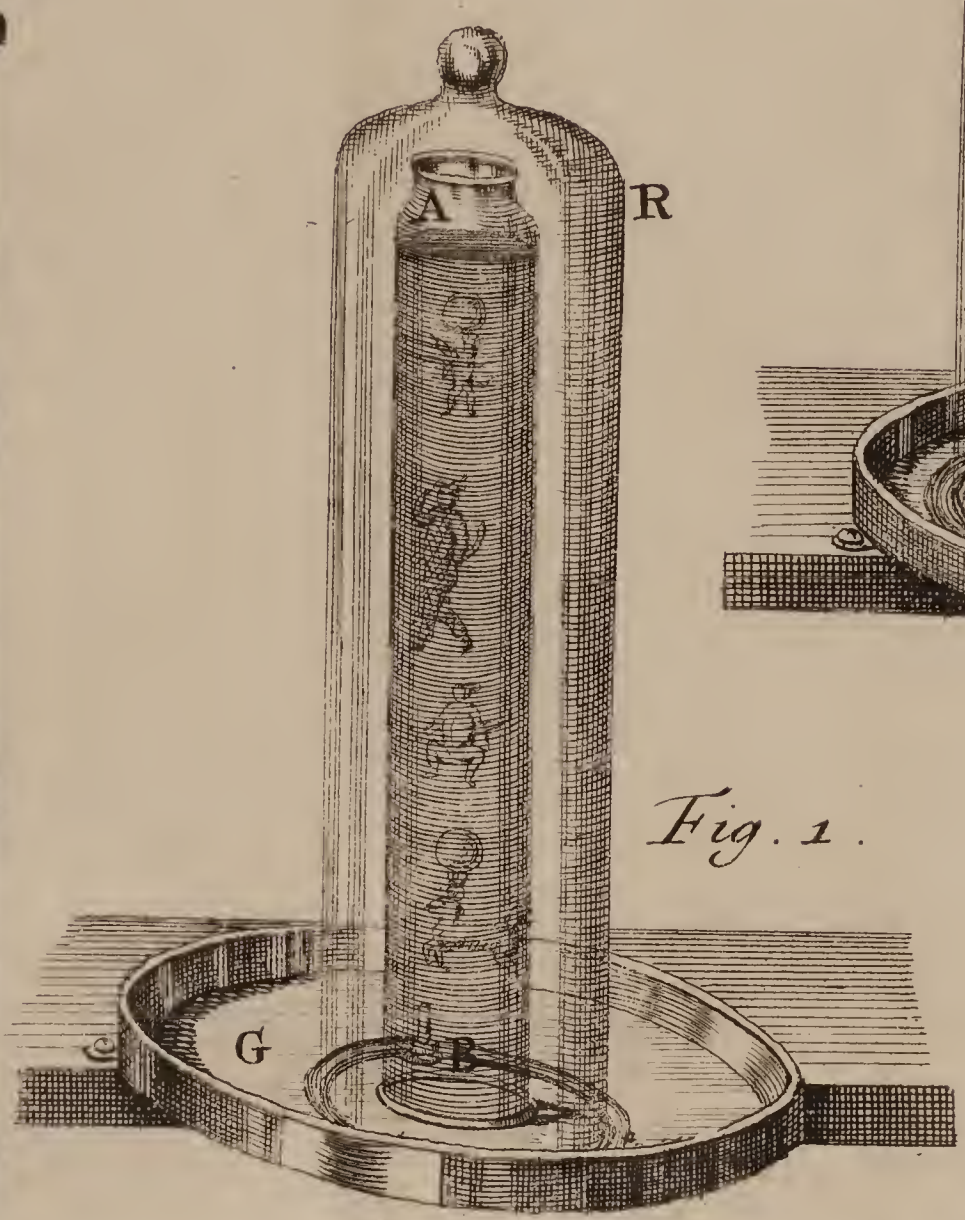


Fig. 1.



Fig. 2.

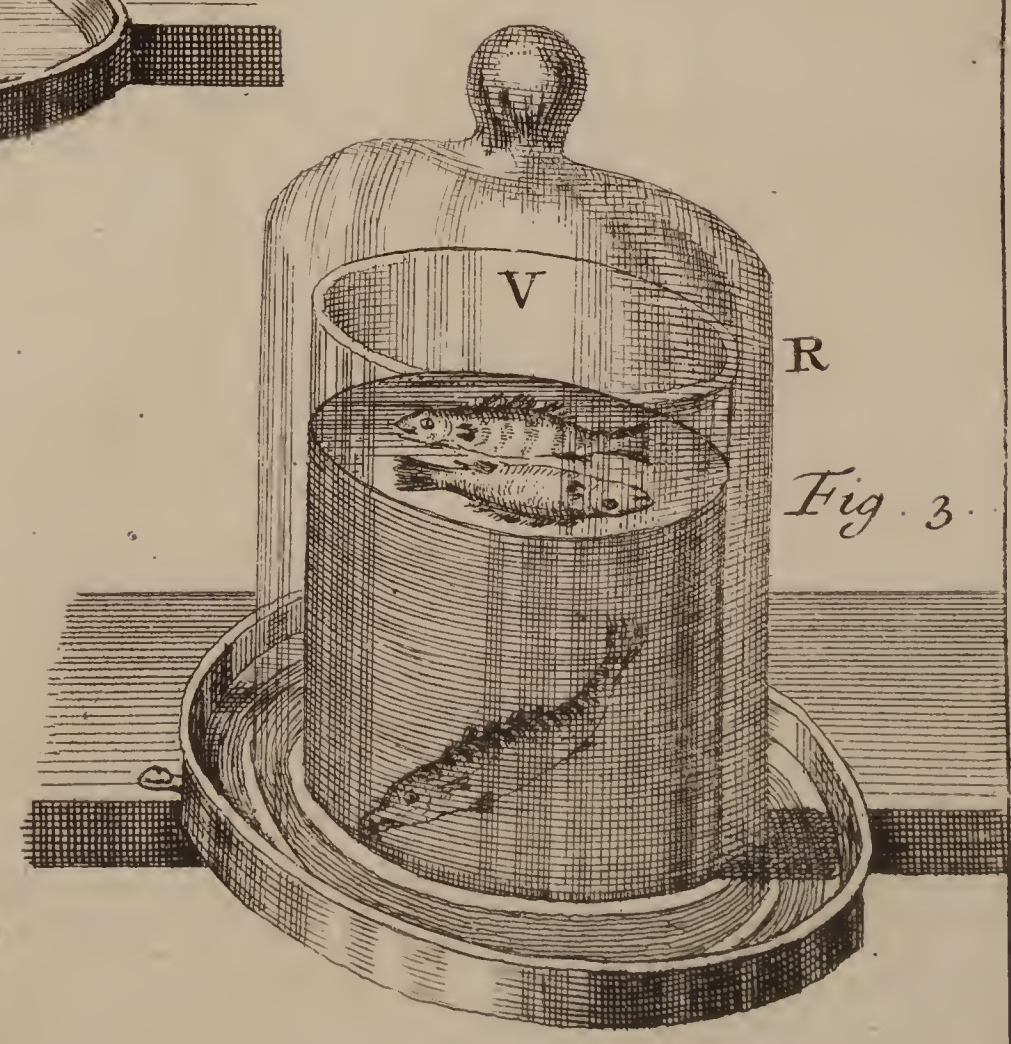


Fig. 3.

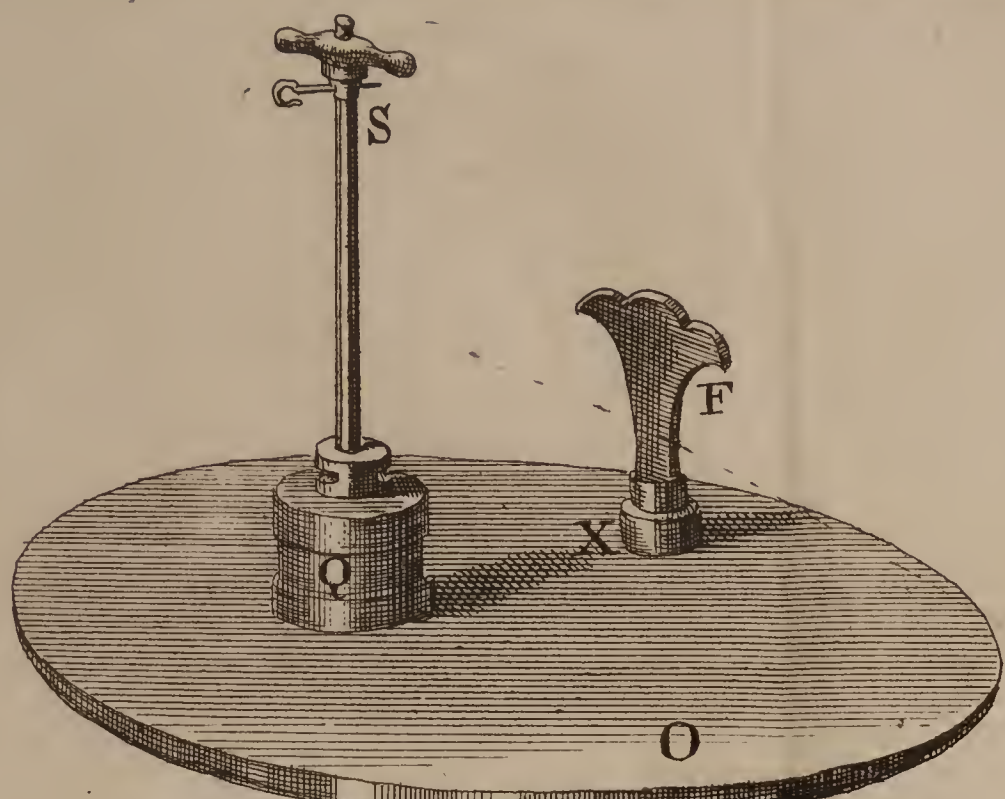


Fig. 1.

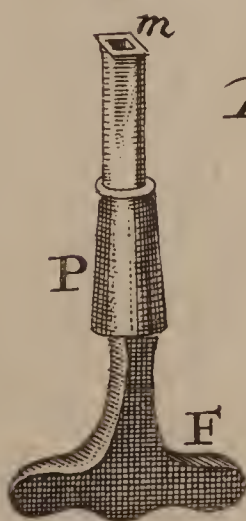


Fig. 2.

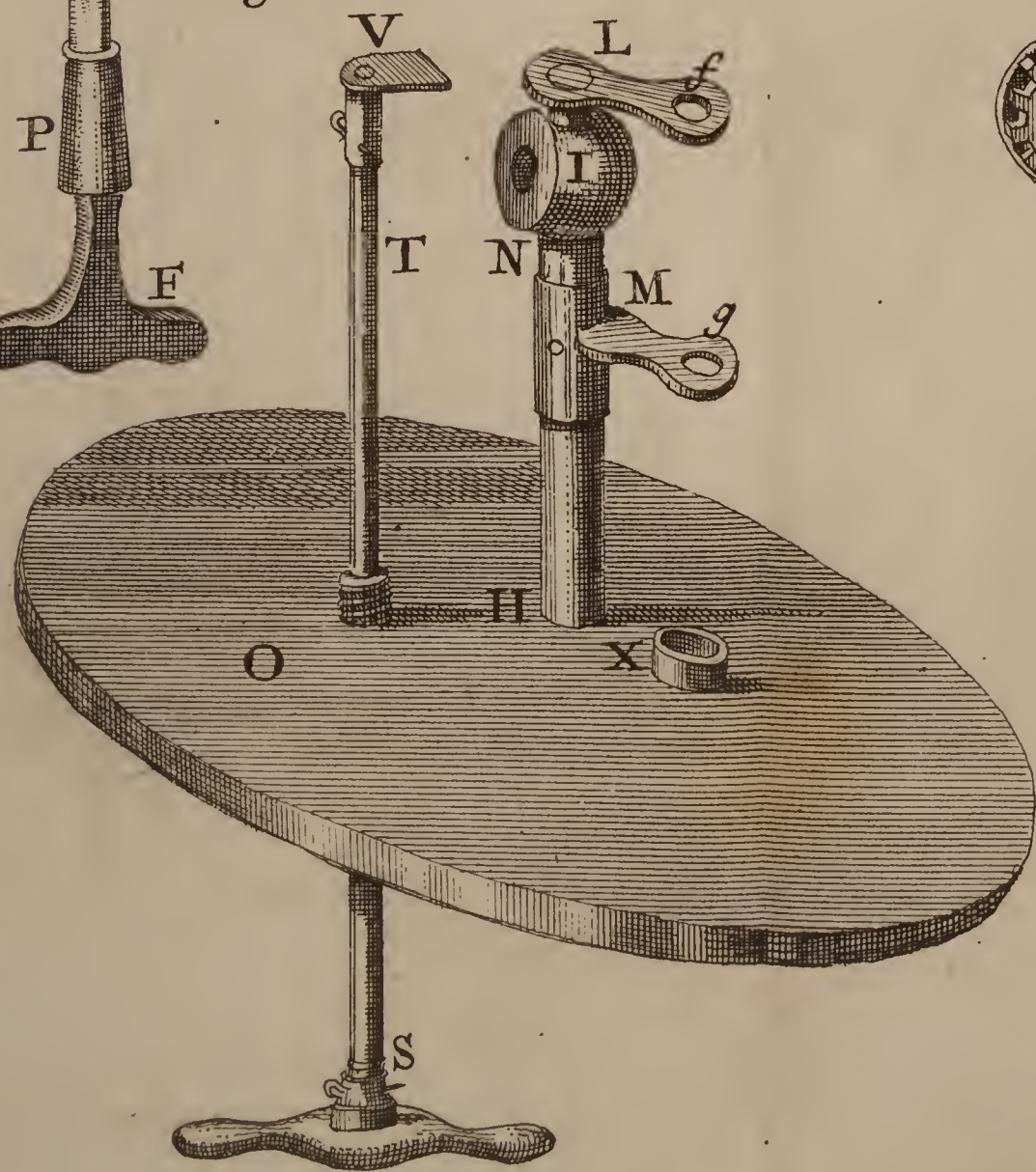


Fig. 4.

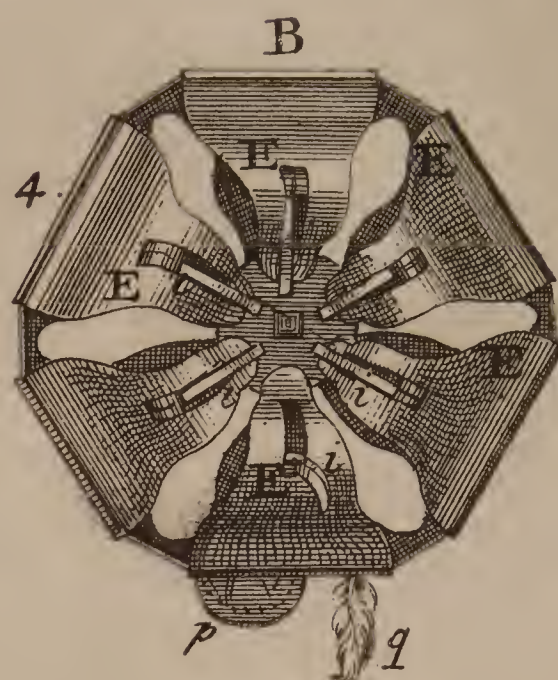


Fig. 3.

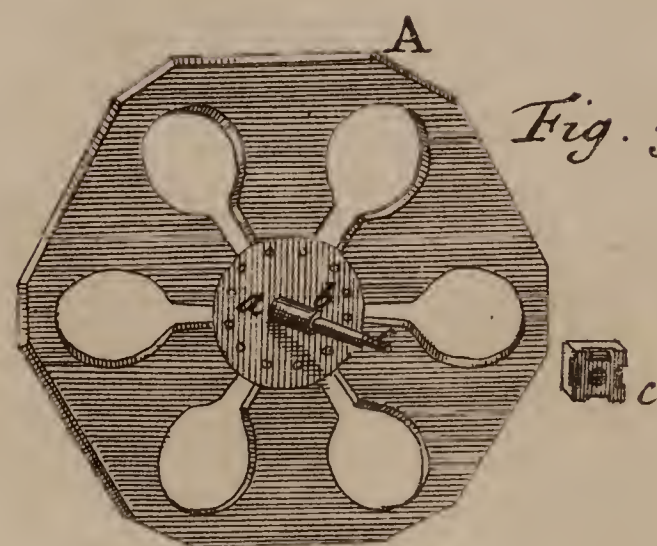


Fig. 5.

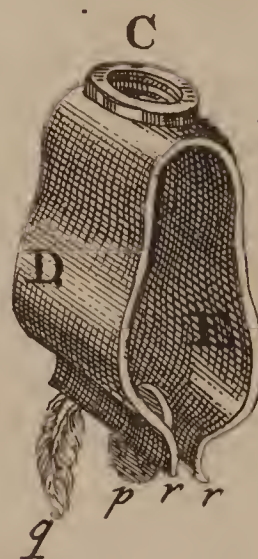
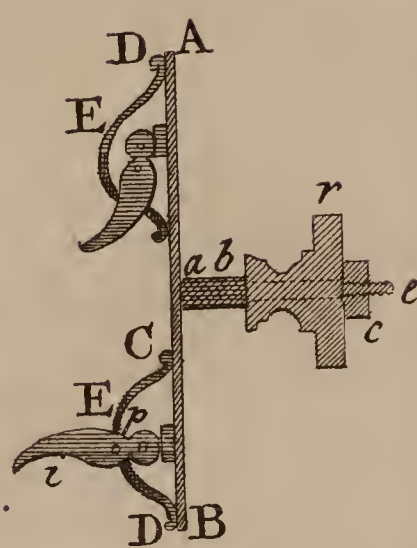
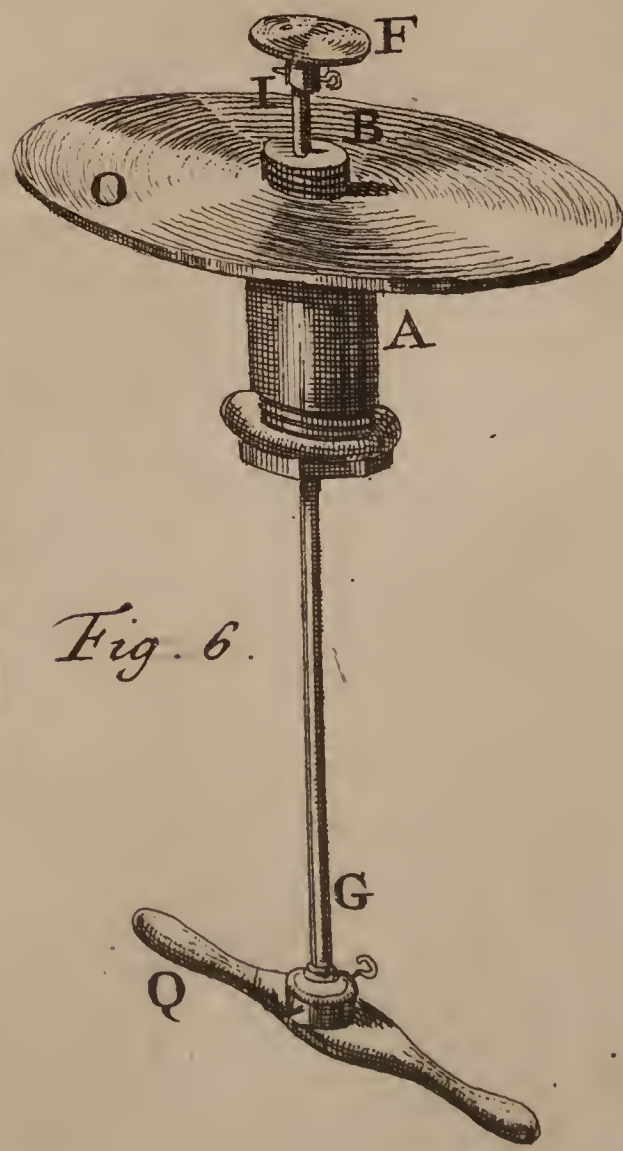


Fig. 6.





above the Orifice, then the Water will run out through the other Leg, for the Reason given in the Explication of the former Experiment. Since the Legs are return'd upwards, the Syphon will not be emptied, when the running out of the Water ceases; and so the Syphon, being once fill'd, is always ready to work it's Effect. The Water runs backward or forward through it, according as it is higher on one Side or the other.

A S Y P H O N,
Whereby Water is rais'd.

Upon the same Principle as the foregoing Machine, is contriv'd the Syphon for raising Water into a Reservoir. The Effect of this Syphon becomes visible by the Help of a Machine made up of two hollow Glass Balls H and I, which are join'd together by the Brass Pipe C D E. The Ball I communicates with the Water to be rais'd, contain'd in the Vessel V, by Means of the Pipe A B, which comes up almost to the Top of the Ball; to the Ball H at the lower Part is join'd the Pipe F G, as long as the whole Pipe A B. 2261.
Pl. 74. F. 2.

The Ball H must be filled with Water through a Hole by a Funnel, and then the Hole must be shut up close.

In such Machines as are applied to Use, for raising Water out of a Reservoir that contains it, the Water is brought away in the Vessel H, and the Communication between the Vessel and the Reservoir is shut up with a Cock. 2262.

EXPERIMENT 3.

Opening the Cock G, the Water will run out that Way, and will ascend through the Pipe A B up into the Vessel I; which being fill'd, the Water is suffer'd to run away to the Place where you would have it; and, by repeating the Operation, the Elevation of the Water continues. 2253.

Opening the Cock G, the Water going out of the Pipe F G, sustains the Pressure of the whole Atmosphere; the Air also presses upon the Surface of the Water in the Vessel V, and it is sustained in the Pipe A B by Means of this Pressure. These Pressures are equal, and if you take from them the Columns of Water which they sustain, you will have the Forces by which the Air is press'd that is contain'd in the upper Parts of the Vessels, which communicate by Means of the Pipe C D E. The Pillar F G, because there 2264.
is

is superadded to it the Height of the Water in the Vessel H, does always overcome the Column in the Pipe A B, therefore the Pressure at G is more diminished than the other, and so overcome by it; and therefore the Water must rise in the Tube A B, and descend down F G.

The common P U M P S.

2265. To render the Action, and Effects of common Pumps visible,
Pl. 74. F. 3. let there be a little Pump made of Glass. Let A B be a Cylinder of Glass, six or seven Inches high, whose Diameter is an Inch and an half. In the Bottom of it join a Tube of any Length, as C D. Let the upper Part of it be stopt up with a Leaden Ball, that the Water may not be able to descend out of the Cylinder A B, but may easily rise into it, by raising up the Ball, which we make use of here instead of a Valve. The Piston is mov'd in the Cylinder A B, which, being surrounded with Leather, exactly fills it's Cavity: There is a Hole in the Piston, which likewise is stopp'd with a Ball of Lead instead of a Valve; so that the Water may rise, but not descend through the Piston.

EXPERIMENT 4.

2266. Push down the Piston to the Bottom; pour Water upon it to hinder the Passage of the Air; if the End D of the Tube C D be immers'd into Water, and the Piston be rais'd, the Water will ascend up into the Cylinder A B *, from which it cannot descend; wherefore, it comes up through the Piston, when it is pushed down. If you raise the Piston again, the Cylinder is again fill'd with other Water, and the first Water is rais'd up into the Wooden Vessel F, which is join'd to the Glass Cylinder, from which it runs out through the Tube G.

2267. Since the Effects of all the Machines, describ'd in this Chapter, depend upon the Pressure of the Atmosphere, the Water will not rise in these Machines to an Height of thirty Feet. The Water
* 2089. might be rais'd to a greater Height, exceeding thirty two Feet *,
* 2129. if, in these greater Heights, the elastic Fluid, spoken of above *, shou'd be separated from it.

HERO's FOUNTAIN.

2268. There are several Fountains, which are call'd *Herc's* Fountains; Plate 69. I shall explain the Construction of one of them.
Fig. 4, 5.

The

The two equal elliptical Vessels A B, and C D, very well clos'd on all Sides, are made of Brass.

In each there is a Division which goes through the Center of the Ellipse, and divides it into two equal Parts.

The Division in the Vessel D C is perpendicular to the Axis of the Ellipse; that of the other Vessel is inclin'd to this Axis; the Disposition of the Pipes, which will be mention'd presently, is the Cause of this Difference.

The upper Plate E F, of the Vessel A B, is hollow'd, to contain Water at the Height of an Inch, or two.

The Vessels are join'd by four Pipes. The first *op* goes through the Cavity B, of the Vessel A B, and has no Communication with it, and descends almost to the Bottom of the Cavity D. The second *st* is folder'd to the upper Part of the Cavity D, and reaches to the Top of the Cavity B, without touching the upper Plate. The third *qr* reaches from the lower Part of the Cavity B almost to the Bottom of the Cavity C. The fourth *xv* coheres with the upper Part of this Cavity C, and reaches almost to the upper Part of the Cavity A.

Lastly there is a Pipe *yz*, which passes through the upper Plate of the Vessel A B, and is so folder'd to it, and descends into the Cavity A in such Manner, that it's End *z* is very near the Bottom of it.

Cocks are join'd to the Cavities at *e, e, e, e*; or there are other Apertures in them, which are stopp'd by Screws, Leathers being put between; the chief Use of which is that the Cavities may be well emptied through them, lest they should rust in the Inside.

EXPERIMENT 5.

Water is pour'd into the Pipe *op*, with which the Cavity D is fill'd; and if you continue to pour the Water in it will ascend along the Pipe *st*, and descend along *qr* into the Cavity C, which is also fill'd, the Air ascending along *xv* and going out through *zy*. Invert the Machine, removing the Screws *e, e*, of the Cavities C and D, and the Water will descend into the Cavities B and A. The Holes *e, e*, being stoppt again, as also the Hole *y* of the Pipe *zy*, set the Machine upright, and pour Water again into the Pipe *op*, 'till the upper Surface of the Machine be covered with Water. Now if the Hole *y* be opened, the Water will spout upwards to an Height almost double the Height *op* (*Fig. 5*;) and the Motion of the Water will continue, 'till the Cavity C is emptied. The Height

2269.

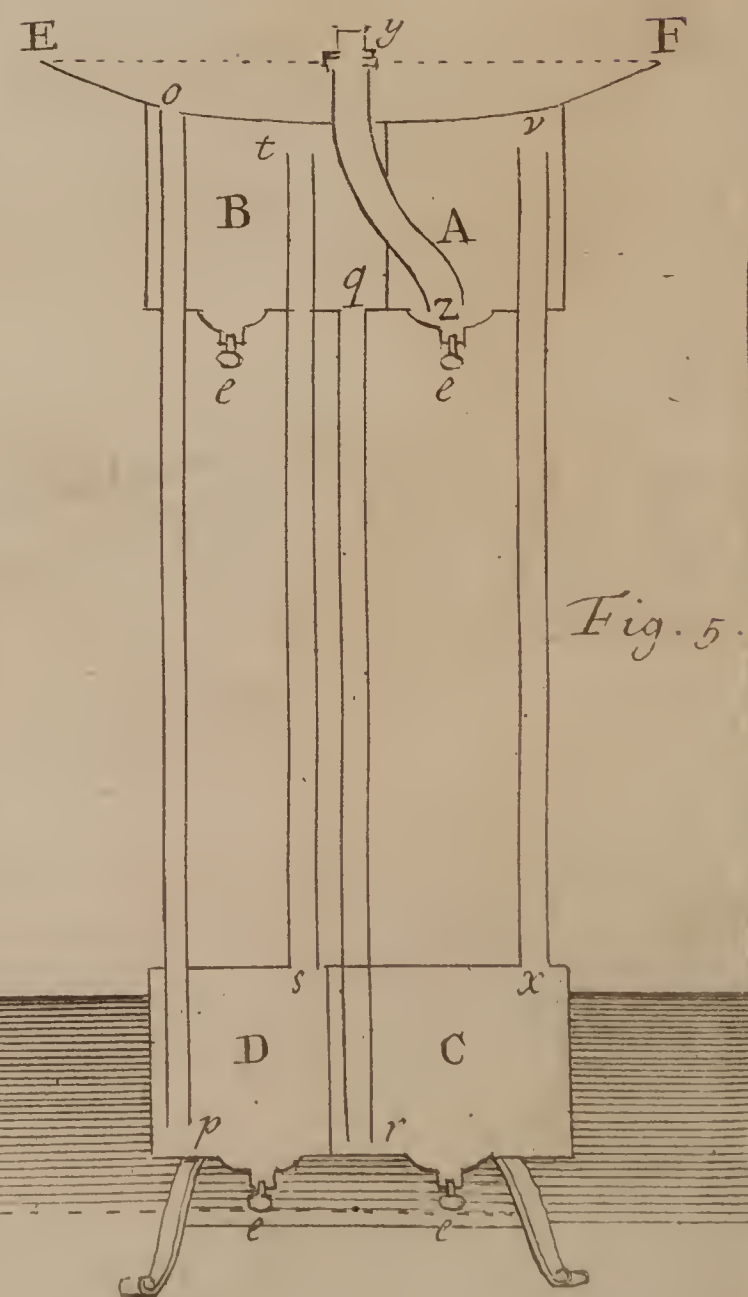
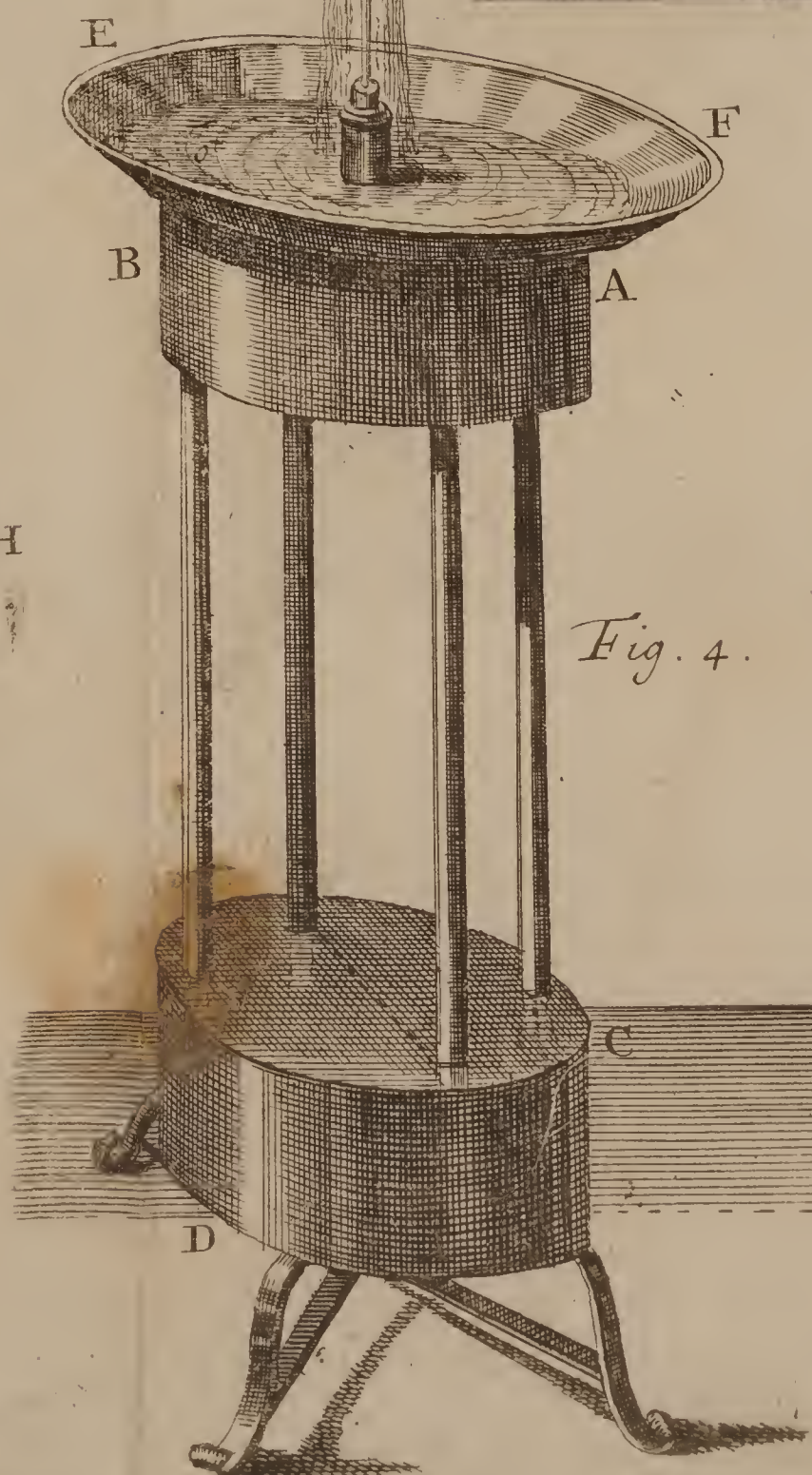
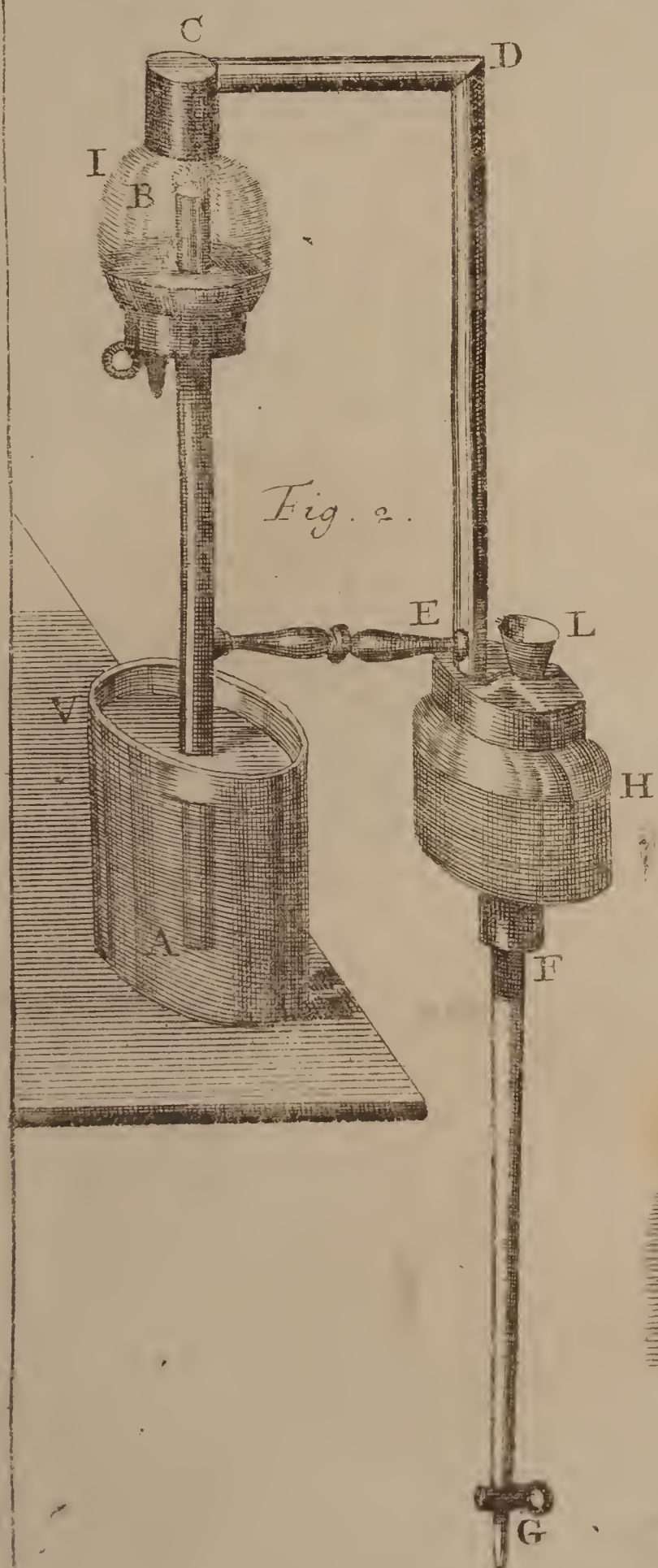
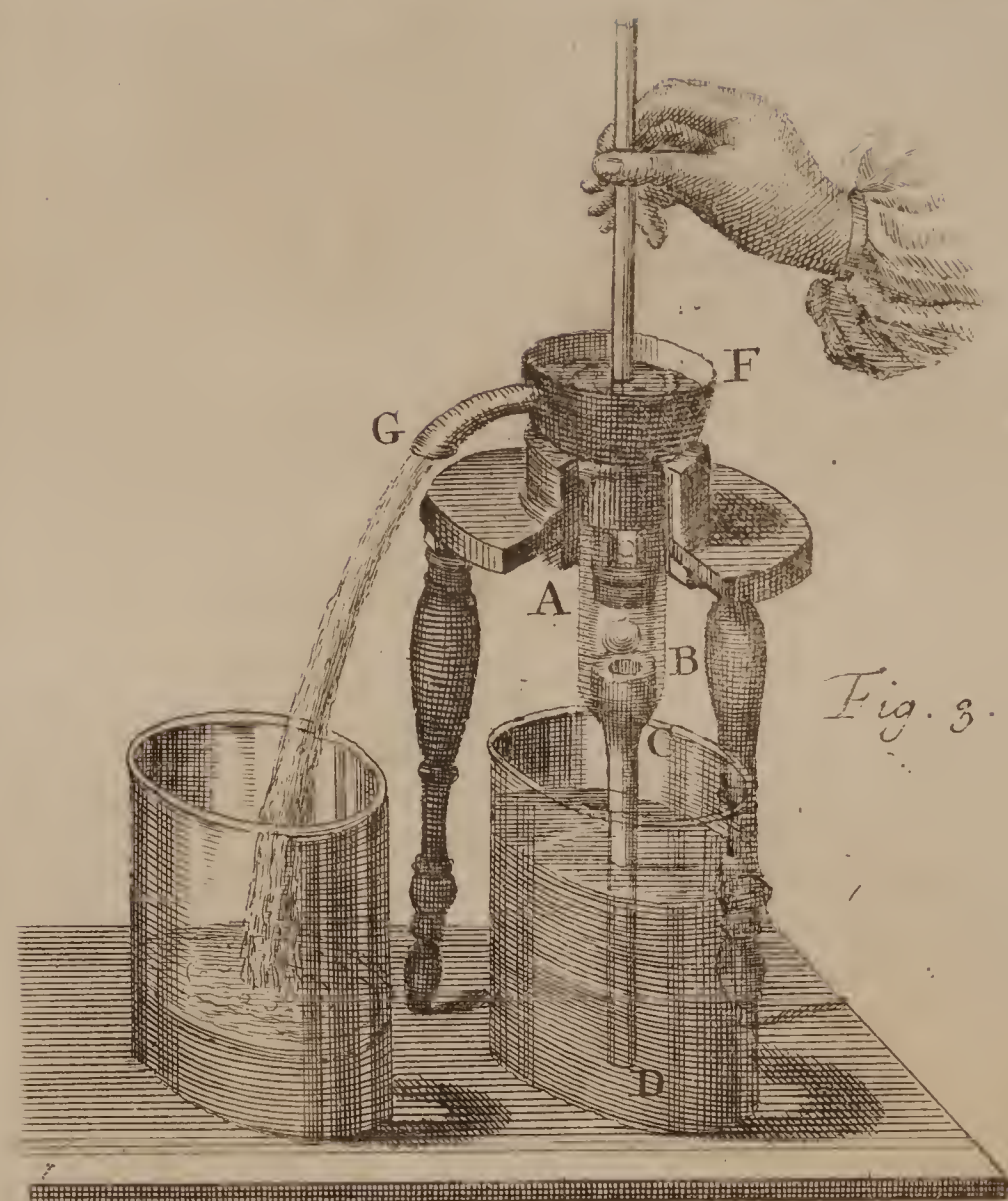
of the spouting Water will be continually diminished, and at the End it will be less than twice the Distance between the Vessels.

2270.

The Effect of this Machine must be attributed to the Compression of the Air in the Vessels. The Pressure of the Atmosphere at o and y , as also the Pressures thence arising in the Vessels themselves, are equal; therefore these Pressures mutually destroy one another, and are not to be taken Notice of in the Examination of the Machine. When at last Water is pour'd into the Pipe op , it is sustain'd in it by the Pressure of the Air contain'd in the Cavity D , and which acts upon the Surface of the Water, which takes up a small Part of the Height of this Cavity; which Air therefore is compress'd by the Weight of the Water of the Height po : I speak of the Pressure, which overcomes the Pressure of the Atmosphere. The Air, contain'd in the upper Part of the Cavity B , communicates with the Air mention'd by the Pipe st , and is compress'd in the same Manner; and this acts upon the Surface of the Water in this Cavity with the same Force. This Pressure must be superadded to the Pressure from the Height of the Water, that we may have the Force, with which the Air, which is contain'd in the Cavity C , is compress'd, as also that which is in the upper Part of the Cavity A , by Reason of the Communication by the Pipe xv . Therefore the Pressure, which acts upon the Surface of the Water, in this Cavity A , is equal to a Pillar of Water, of almost double the Height of the whole Machine; and therefore the Water spouts, through the Hole at y , as if it were press'd by such a Pillar; that is, it rises to an Height, which wants but little of the Height of this Pillar *.

* 1588.

This Height is continually diminished; for the Pillars of Water, which compress the Air, are continually diminish'd; because the Water is encreas'd in the Cavities C and D , and it's Height is diminished in the Cavity B . At the same Time the Cavity A is continually emptying, and the Water rises through a greater Space, before it comes to y ; and it is therefore driven to a less Height above y .



C H A P. VII.

Of the Undulatory or Wave-like Motion of the Air, as likewise concerning Sound.

*I*F the Air be any how agitated, the Particles mov'd go out of their Place, and cause the Particles next to them to possess a less Space; and whilst the Air is dilated in one Place, it is compress'd in the Place next to it. The compress'd Air, whilst, by Reason of the Elasticity being encreas'd by the Compression, it expands itself again, does not only return to it's first State, but is itself dilated by the Motion acquir'd by the Particles receding from one another beyond their first Distance. 2271.

The Air being first dilated by that Motion, returns to it's first State, and the Air towards other Parts is compress'd. This again happens, when the Air last compress'd expands itself, and thereby a new Compression of Air is produc'd. Therefore from any Agitation there arises a Motion analogous to the Motion of a Wave on the Surface of Water *. And the Air thus compress'd, with a Dilatation following, is call'd by that same Name, viz. a Wave of Air *. * 1737. * 1738.

Compress'd Air dilates itself every Way, and the Motion of these Waves, is the Motion of a Sphere expanding itself, just as these Waves move circularly on the Surface of the Water *. 2272. * 1740.

Whilst a Wave moves in the Air, wherever it passes, the Particles are mov'd from their Place and return to it, running through a very short Space in coming and going. 2273.

To explain the Laws of this Motion, let us conceive Particles of Air to be plac'd at equal Distances, *a, b, c, d, &c.* and *f* in a right Line. Let the Wave move along that Line, and suppose it to be come forward, as far as between *b* and *p*; and that the Air is dilated between *b* and *h*, but compress'd between *h* and *p*; as all this is represented in Lines. 2274. Pl. 75.F.1.

The greatest Density is at *m*, the Middle Point *t* between *h* and *p*, and the greatest Dilatation is in the Middle *e* between *b* and *h*. 2275.

Wherever the neighbouring Particles are not equally distant, by the Action of the Elasticity the less distant Particles are press'd towards those that are more distant *; and this Pressure, setting aside all Motion acquir'd, must be first examin'd into. 2276. * 2111.

2277. Between b and e there is a Pressure from b towards e , that is, conspiring with the Motion of the Wave, and another such between m and p .

2278. But there is a contrary Pressure between e and m , from m towards e .

2279. At m and e , where the Directions of these Actions are chang'd, the opposite Actions destroy one another; because the adjacent Particles are suppos'd to be equally distant.

2280. In the Places b , h , and p the Difference of the Distances of the adjacent Particles is the greatest of all; and therefore the Action of the Elasticity towards one Part is the greatest of all.

2281. From hence we gather that a Particle according to it's different Place in a Wave suffers a different Action from the Elasticity by which it's Motion is generated, accelerated, diminish'd, or destroy'd. Therefore the Direction of the Motion of a Particle cannot be determin'd from the Direction alone of the Action mention'd, and that does not always agree with this Direction, and the Motion of every one of the Particles is chang'd every Moment.

2282. All the Particles between b and p are carried according to the Order of the Letters. The Particles, between b and p , continue their Motion in this Direction; and the rest between b and b return towards b , as we shall see hereafter.

2283. These continue in the Motion by which they return, until, by the Action of the Elasticity, whose Direction is chang'd in the Point e , the Motion acquir'd anew be destroy'd; in which Case a Particle, as b , returns to Rest in it's former Situation. In the next Moment the Particle c comes to Rest in it's former State, but p comes on to q , as in Line 2; and in equal Moments, the Wave successively has all the Positions, as you see here in the Lines 1, 2, 3,

2284. &c. and 13; and whilst the Wave comes from the Position in the Line 1, to the Position in the Line 13, it runs through it's whole Breadth. The Particle p in this Motion goes and comes, and it's Motion is sensible in this Figure; and this Particle goes successively through all the Positions of the Particles in the Wave, as is manifest.

2285. All the Particles are successively agitated with a like Motion: And if the Time, in which a Wave runs through it's Breadth, be divided into so many Parts as there are Particles in the Breadth of the Wave, every Particle will be found in that Position in which the following Particle was the Moment foregoing, which was longer in Motion by one such Moment.

Chap. 7. *of Natural Philosophy.*

45

The Motion of any Particle, as p, in going backwards and forwards, is analogous to the vibrating Motion of a Pendulum, whilst it performs two Oscillations ; that is, once goes and once returns.

2286.

A Pendulum descends in it's Oscillation, and the Motion acquir'd conspires with the Action of Gravity, and is accelerated by it, until it comes down to the lowest Point of the Arch to be describ'd, that is, to the Middle of the Way to be mov'd through ; the Pendulum goes on by the Motion acquir'd, which is destroy'd by the Action of Gravity, whose Direction changes in this Point, whilst the Body rises up the other Part of the Arch to be describ'd : This Body goes back with the same Laws.

2287.

The Particle *p* is mov'd by the Elasticity, and it's Motion is accelerated by the Action of the Elasticity, until it comes to the Situation of the Particle *m*, in the Line 1 * ; which Situation appears in the Line 4, in which the Particle *p* takes up the middle Point of the Space, to be run through, in coming and going. Though the Elasticity acts contrary to the Motion acquir'd *, yet it continues it's Motion, until the Motion be quite destroy'd by the Action of the said Elasticity ; which happens when it has gone through a Space equal to that, in which it was generated ; then the Particle *p* is in the Situation, appearing in the Line 7, which answers to the Situation of the Particle *b* in the Line 1. Then the Particle returns by it's Elasticity, and is accelerated, until it has acquir'd the Situation of the Particle *e* of the Line 1 *, as in the Line 10 ; that is, until it comes again to the Point that is in the Middle of the Way to be run through, as in the Line 4. The Particle continues returning until the whole Motion be destroy'd by the Action of the Elasticity, whose Direction is again chang'd * ; and then the Particle returns to it's first Position, as in the Line 13, and there not being agitated by any new Motion, remains at Rest. All which Things flow from what is demonstrated in the first following Scholium. Therefore *when the Motion of a tremulous Body, which agitates the Air, ceases, there are no new Waves generated, and the Number of the Waves is the same as the Number of the Agitations of that Body.*

2288.

2277.

2278.

2278.

2279.

2289.

If the Action of Gravity shou'd cease after two Vibrations of a Pendulum, as in the Air after the going and returning of a Particle, the Action of the Elasticity upon that Particle ceases ; the Motion of a Particle of Air, wou'd in all Things agree with the Motion of the Pendulum. In the middle Point of the Arch, which is to be run through by the Oscillation, there is no Action of Gravity, and
the

2290.

- the Direction thereof is chang'd; in the middle Point of the Space to be mov'd through, by the Particle p in it's going and coming, in which it is in the Line 4 and 10, the Situation of this Particle answers to the Situation of the Particles m and e , in the Line 1, in which Points there is no Action of Elasticity, and it's Direction is chang'd *. In a Pendulum, the more a Body oscillating is distant from the lowest Point, or middle of the Arch to be describ'd, the more does the Force of Gravity act upon it; also the more distant the Particle p is from the middle Point of the Space to be run through, the greater is the Action of the Elasticity upon it, and in the Lines 1, 7, and 13, in which the Particle is most distant from the Point abovementioned, the Situation of it agrees with the Points b , b , and p , in the Line 1, in which the Action of the Elasticity is greatest of all *.
- * 2279. By which Law is determin'd the Action of the Elasticity, since it increases when the Distance from the often-mention'd middle Point increases, from the Law of the Elasticity of the Air itself, whose Particles fly from one another with a Force which is inversely as the Distance between the Centers of the Particles *; and we demonstrate in the first Scholium annexed to this Chapter, that the Action of the Elasticity upon a Particle, as p , increases or diminishes in Proportion to it's Distance from the middle of the Space to be run through.
2280. For which Reason, *every Particle in it's Motion goes and returns, according to the Law of the Motion of a Pendulum oscillating in a*
- * 2291. *Cycloid* *.
2111. We demonstrate in the same Scholium, that *the Velocity of a Wave is equal to that Velocity which a Body acquires in falling from one half the Height that the Atmosphere would have, if, whilst the Quantity of the Air remains the same, it should every where have that Density, which it has in the Place wherein the Wave moves.* And the Demonstration obtains whatever be the Breadth of the Wave, and whether the Particles in going and coming run through a greater or less Space; whence it is evident that *all Waves move with the same Velocity*; namely as long as the said Height of the Atmosphere is not alter'd, supposing it to be every where of the same Density.
2292. But this being chang'd, *the Squares of the Celerities of the Waves are in the Ratio of the Heights* *. But this Height often varies; for the Density of the Air often alters *the Elasticity remaining the same*; and the Elasticity may be chang'd while the Density remains the same; lastly they very often both together change.
- * 414. 2293. 374. 2296.

In the first Case, viz, when the Elasticity remains, and the Density varies, whilst the Air is suppos'd every where of the same Density, the Height is chang'd, but the Quantity of the compressing Air does not vary; because the Weight thereof is equal to the Elasticity *: And the Height is as the Space taken up by the Air; * 361. and so is inversly as the Density †; wherefore *the Squares of the* † 1464. *Velocities of the Waves are inversly as the Densities* *. * 2295.

When the Density remains the same, but the Elasticity varies, the Height of the Atmosphere is chang'd in the Ratio of the compressing Weight, that is, in the Ratio of the Elasticity *. There- * 361. fore *the Squares of the Velocities of Waves are as the Degrees of Elasticity* *. * 2295.

If both the Velocity and Density differ, the Squares of the Velocities of the Waves will be in a Ratio compounded of the direct Ratio of the Elasticity †, and of the inverse Ratio of the Density *. † 2297. * 2296.

If the Density and Elasticity increase or decrease in the same Ratio, the inverse Ratio of the Density destroys the direct Ratio of the Elasticity, and *the Velocity of the Waves will not be chang'd*. * 2299.

This last Case happens in the Compression of the Air arising from other Air mixing with it *, whereby, if the Tenor of the Air re- * 2109. mains the same as to the rest, the Height of the Atmosphere, supposing it to be every where of the same Density, is not alter'd; for it is reduc'd into a less Space in Proportion to the superadded Weight. Therefore *from the chang'd Height of a Column of Mer-* 2300. *cury, which is sustain'd in a Tube exhausted of the Air* * *by the Pres-* * 2085. *sure of the Atmosphere, which shews that the Weight, by which the Air is compress'd near the Earth, is chang'd, we cannot be cer-* 2301. *tain whether the Velocity of the Waves does alter. For the same Reason the Waves are mov'd with the same Velocity in the Top of a Mountain as in a Valley, if the Tenor of the Air does not differ ac-* according to the greater Height *. * 2123.

That *Waves move faster in Summer than in Winter* is deduc'd from the Elasticity of the Air being increas'd by Heat *. * 2302. * 2117.

The Height of the Atmosphere, supposing it to be every where of the same Density, is found out by measuring the Height of the Column of Mercury in the *Torricellian* Tube, which is balanc'd by the Pressure of the Atmosphere *, and by comparing the Den- * 2085. sity of the Air with the Density of the Mercury; which may be done by weighing the Air *. And when the Height of the Air is * 2164. found out, the Velocity is had by Experiments of Pendulums, which a Body acquires in falling from one half that Height *. * 415.883.374.

The

2304. The Motion of the Air, which is consider'd in this Computation, depends wholly upon the Elasticity, and the Computation would be exact, if the Particles themselves had not a sensible Proportion to the Interstices between them ; but if we suppose here that the said Proportion is sensible, the Motion of the Waves will be swifter ; for Motion is propagated through solid Bodies in an Instant.

2305. But we have consider'd the Particles of the Air as Points, and the Velocities found out upon this Supposition, must be increas'd in Proportion of the Matter to the Interstices, in order to have the true Velocity.

2306. Wherefore so long as the same Air preserves it's Density, the Augmentation of the Velocity is in the same Ratio with the Velocity itself.

2307. But if the Density is chang'd, the Augmentation is not only in the Ratio of the Velocity, but also in the Ratio of the Matter to the Matter in the same Line, which is the Ratio of the Cube Root of the Density.

2308. If the Air be different, this Rule does not obtain, for the Particles themselves, when the Density remains the same, may have a different Density ; and the Ratio of the Diameters of the Particles to the Interstices will be alter'd.

2309. The Motion of the Waves in the Air produces Sound ; but before we treat concerning this, we must premise a few Things in general relating to the Sensations.

2310. So strict is the Union between the Body and the Mind, that some Motions in the Body do as it were cohere with certain Ideas of the Mind, and they cannot be separated from each other. New Ideas are every Moment excited in the Mind, by the Motion of the Nerves, and such are the Ideas of all sensible Objects ; yet we find nothing common between the Motion in the Body and the Idea in the Mind. We cannot perceive their Connexion, or whether there be any at all. There are innumerable Things in Nature hidden from us, which even our Ideas cannot attain to. But this Connexion does not relate to Physicks.

2311. When a Sensation is to be explain'd in Physicks, we ought to shew how the Motion of a Body, which Causes Sensation, acts upon our Nerves.

2312. Therefore three Things relating to Sound are to be consider'd ;
1. we must determine the Motion in a Body which produces Sound ;
2. We must shew how these Motions are transfer'd to us ; 3. Lastly we must explain what happens in us.

The Parts of Bodies, which emit Sound, are put into a tremulous Motion; for non-elastic Bodies, when struck, do not produce Sound. This tremulous Motion is also undoubtedly in stretched Chords or Fibres, from whence proceeds the Sound. This tremulous Motion is very sensible in large Bells, and in many other Bodies; it is visible from the following Experiment with a Glass Bell, which gives a Sound.

2313.

EXPERIMENT 1.

A thin Glass Bell, which has a Knob at Top, that it may be held in the Hand, is struck, and the Edge of it is brought near any solid Body at rest; if the Distance be small, the Bell will, by Means of it's tremulous Motion, strike against this Body several Times.

2314.

Yet the Sound does not immediately depend upon this visible Motion, but upon another tremulous Motion, with which the smaller Particles are affected, in the Motion mention'd.

2315.

EXPERIMENT 2.

The elastic Iron Plate A C B, being suspended, is put into a tremulous Motion which is visible, if the Ends A and B are brought together, and suddenly let go; yet no Sound is heard: But if it be struck on the Sides, which does not put it into a tremulous Motion that is visible, there is a Sound produc'd.

2316.

Pl. 76. F. 1.

A Body that is struck, continues to give a Sound some Time after the Blow; for the agitated Fibre will continue it's Vibration some Time, on Account of the Elasticity.*

2317.

* 1332.

Sound also ceases when the tremulous Motion ceases.

2318.

From a Body, thus agitated, Motion is transfer'd to the Ear by Means of the Air; for Experience shews that this is the Vehicle of Sound.

2319.

A MACHINE,

Whereby Experiments concerning Sound are made.

The Machine A, to which is join'd the little Bell C, (which is represented separately in Fig. 5, that it may the better appear how it is to be join'd to it,) contains several small Wheels, to which Motion is communicated by a Spring, as in Watches; and which move the small Hammers *m, m*, that strike the Bell alternately. It is requir'd that this Motion be continued four or five Minutes, before the Spring be let loose.

2320.

Pl. 75.

F. 2. 5.

2321. By the Plate *e*, the Motion of the Wheels, and the Hammers, is stopp'd, or continu'd ; this depends upon the Position of the Plate which may be varied, whilst it is moveable about *c*, and can retain the Plate *d*, which coheres with an Axis, and in it's Motion goes and returns round a Center.

EXPERIMENT 3.

2322. This Machine coheres with the Leaden Stand *D*, and, the small
Fig. 2. Cushions *E, E*, being put between, is put upon the Plate *G* of the Air-pump, and is cover'd with the Glafs Receiver *R*, open at Top. This Aperture is clos'd by the Cover *O*, to which is fasten'd the
* 2155. Collar of Leathers *P*, which the Brafs Wire *S T* goes through * ; to the End *T* of this Wire is join'd the Plate *B*, which is so bent and cut in, that by turning the Handle, the Position of the Plate *e* may be alter'd ; whereby the Hammers are retain'd, or let loose, as you please. The Hammers being fix'd, the Air is exhausted from the Receiver, the Hammers are let loose, and no Sound is heard.

2323. All the Sound cannot always be extinguish'd, but it may be so weaken'd, as to be perceiv'd only by those, whose Hearing is pretty quick.

2324. The Mercurial Gage also, in this Experiment, does not shew that all the Air is exhausted ; for when the Mercury is come to it's greatest Height, the Motion of the Pump must be continued, that the Sound may be extinguish'd, or weaken'd as much as possible ; by which is confirm'd what we said before, that the Density is diminish'd, the Elasticity remaining the same *.

- * 2190. A small Quantity of Air being let in, we immediately perceive
2325. a Sound, which is increas'd with the Air that is let in. This Experiment puts it out of all Doubt, that Sound is propagated by Air, but in this Motion the Air is not carried from one Place to another ;
2326. whence appears what we said, that *Sound depends upon the undulatory Motion of the Air* ; by which is confirm'd, that *Sound arises from the tremulous Motion of Bodies*.

2328. But as this tremulous Motion is easily communicated from one Body to another, *The Conveyance of the Sound, from the tremulous Motion of the Fibres, is very remarkable* ; and how far the Communication of this Motion extends itself, will appear from one Experiment only.

EXPERIMENT 4.

Things being dispos'd, as in the foregoing Experiment, and the Air being exhausted, and the Hammers being let loose, the Handle M is turn'd in such Manner, that the Plate B may touch the Plate e, but not alter it's Position ; at that very Moment a Sound is heard ; the Sound of the Bell indeed is weak, but the Sound of the Wheels is perceiv'd very distinctly ; the Plates being again separated the Sound immediately ceases. 2329.

In the third Experiment, before the Air was exhausted, and after it is again let in, the Sound might be perceiv'd, though the agitated Air had no Communication at all with the external Air ; whence it follows, that *the undulatory Motion of the Air communicates a tremulous Motion to the Fibres of Bodies, whereby Waves are generated in the exterior Air.* But in this Case the Sound is very much weaken'd. 2330.

As Sound is propagated through solid Bodies, so likewise is it through Fluids ; but in this last Case it is also very much weaken'd. 2331.

EXPERIMENT 5.

The Machine describ'd above * is inclos'd in the Glass V, the Hammers m, m, being first let loose ; the Glass is clos'd with the Wooden Cover O, and the Water is hinder'd from getting in by soft Wax. This Glass is put into a greater Glass B, which contains Mercury in it to the Height of one, or two Inches, and the Glass B is fill'd with Water. A Sound is heard, but it is weak. 2332. Pl. 75.F.3.

But there is no Communication between the Bell and the external Air, unless through the Fluids, Water or Mercury. * 2320.

The Fluid communicates a tremulous Motion to the Glass itself, in which it is contain'd, and to the Air, which is upon the Surface of the Water. 2333.

In all these the undulatory Motion comes to the Ear, and goes into a Canal, in the external Part of the Ear ; this external Part is terminated by a very thin, stretch'd Membrane, call'd the Tympanum, or Drum of the Ear, and which separates the external Part of the Ear from the internal. The Particles of Air, which are near this Membrane, when the undulatory Motion reaches them, strike the Drum of the Ear, and communicate a tremulous Motion to it, which is transfer'd to the Air inclos'd in the inward Cavity of the Ear ; some smaller Bones are mov'd, by the Agitation of the Drum ; the undulatory Motion is propagated through certain small Canals, 2334.

which are twisted in a peculiar Manner, and the whole bony Surface of this Cavity is struck by the Particles of Air, which are in Motion. By all these Motion is easily communicated to the auditory Nerve, which coheres with the Organ, of which we are speaking, and which goes into the Cavity itself of it.

2335. The Structure of the Ear is wonderful, but as we are not acquainted with the Use of the peculiar Parts, the general Things only, which we have taken Notice of, belong to our Purpose.

2336. *The Celerity of Sound is the same as the Celerity of Waves, which strike the Ear*, and to this must be refer'd what has been said of their Celerity *. In respect to Numb. 2293 it is to be observed, that the Celerity of Sound can no Way be determin'd by Calculation *; for the Proportion between the Diameters of the Particles and the Interstices between them, is not known; but the Celerity of Sound may be immediately determin'd by an Experiment.

* 2293. 2294.
2296 2297.
2298. 2299.
2300. 2301.
2302. 2305.
2306. 2307.
2308.
* 2303. 2304.
2337. If a Flash of Fire goes off at Night with a Noise, and a Spectator stands at any known Distance from the Fire, who, with a short Pendulum, measures the Time between seeing the Light, and hearing the Sound, he will have the Celerity of the Sound; for the Motion of Light, at least, through the Space as such an Experiment can be made in, is instantaneous.

2338. By such an Experiment made in *France*, it appear'd, that Sound mov'd 1080 *French* Feet, that is, 1117 *Rhinland* Feet in one Second of Time: Which Velocity differs little from that, which *Durham* determin'd from many Experiments, in a Space exceeding twelve *English* Miles; according to whom the Space run through in one Second is 1100 *Rhinland* Feet: But this Celerity is not constant *.

* 2302.
2339. If at the same Time in which the Velocity of Sound is determin'd by this Method, you find out the Space mov'd through by the Elasticity *, the Acceleration of the Sound will be had from the Thickness of the Particles.

2540. *The Celerity of Sound is equable* *; yet in going through a greater Space it is sometimes accelerated or retarded †, from the different repellent Force, which the Particles sometimes have in different Places *. But this is deduc'd rather from Reasoning than Experience, because the Constitution of the Air does not differ enough in neighbouring Places.

* 2294.
† 2296.
* 2117.

2341. *The Celerity of Sound varies as it goes with the Wind, or against it.* By the Wind a certain Quantity of Air is carried from one Place to another; the Sound is therefore accelerated as long as it

moves

moves through that Part of the Air, if the Direction of the Sound be the same with the Direction of the Wind ; in which Case the Velocity of the Wind must be superadded to the Velocity of Sound, which has been taken Notice of.

But the Velocity of the most violent Winds, which is strong enough to root up Trees, and blow down Houses, is less than a thirtieth of the Velocity of Sound, if with *Mariotte* we suppose, the most violent Wind to run through only thirty two Feet in one Second. 2342.

According to others the Velocity of Wind is much greater, and therefore the Acceleration of Sound is greater, which agrees better with Observations. 2343.

By the Way of arguing it is also prov'd that Wind retards the Motion of Sound. 2344.

The Spaces which the Particles run through, as they come and go, may be increas'd and diminish'd by the Wind ; therefore *the Sound may be heard at a greater or smaller Distance, according to the Direction of the Wind.* For in the Air which is mov'd by the Wind, there is a certain, small mutual Access of the Particles, whilst the hinder Air drives on that which is before it ; by this the Elasticity of the Air is increas'd, and the Direction of this mutual Motion conspires with the Direction of the Wind. 2345.

The Intensity of Sound depends upon the Strokes of the Air upon the auditory Nerve ; and these Strokes are as the Quantities of Motion of the Particles striking. 2346.

These Forces are as the Number of the Particles striking against the Drum of the Ear at the same Time, and as the Squares of the Velocities of these Particles *. 2347.

Therefore *in determining the Intensity of Sound, the Density of the Air must be consider'd, the Velocity of the Sound, the Space mov'd through by the Particles in going and returning, and the Number of the Waves striking the Ear in a certain Time.* * 757. 2348.

All things remaining as before, if the Weight by which the Air is compress'd be only chang'd, the Space mov'd through by the Particles in going and coming will not by that be chang'd, which only varies upon the Augmentation or Diminution of the tremulous Motion of the Parts of a Body ; nor will the Number of the Waves be chang'd, for these also depend upon the tremulous Body ; neither is the Velocity of the Sound alter'd *, setting aside the Acceleration, * 2300. mention'd in Number 2305. which is not to be consider'd here, because in this Place the Velocity we are treating of, is that with which

- which every Particle is mov'd ; therefore the Density only varies, that is, the Number of Particles moving in a given Time is only chang'd, and *the Intensity of the Sound is chang'd* in this Ratio * ; that is, in the Ratio of it's Density, which is *in the Ratio of the compressing Weight* *.

It appears by Experiment that the Intensity of it is encreas'd.

EXPERIMENT I.

2350. The Board, part of which is represented separately at E, is put
Plate 75. into the Machine NM, in which the Air is compress'd *. Upon
Fig. 4, 5. this Board we put the Machine A †, a Leather being put between,
* 2216. which we made Use of in the third Experiment of this Chapter * ;
† 2320. and that it may not be remov'd from it's Place, the Leaden Stand
* 2322. D has two Holes in it ; that Pins, fasten'd to E, one of which is
seen at *f*, may go into these Cavities. To the Cylinder NM is
join'd the Collar of Leathers *p*, through which the Brass Wire
ST goes *, to which is fasten'd the Plate B, which we made Use
* 2155. of in the third Experiment *, but it is applied to the Wire in ano-
* 2322. ther Manner ; by this, in this Case, as in that, the Hammers are
kept from moving, or they are let loose, by turning the Handle Q.
The Cylinder MN is clos'd by the Cover O, and the Air is com-
* 2224. press'd as much as you please *, and the Machine is again put upon
it's Stand G. The Hammers being let loose, the Sound is heard
distinctly, and the better, the more the Air is compress'd. If you
open the Cock, and let the Air out, and shut it again, the Sound
is faint.
2351. As the Intensity of the Sound is greater in compress'd, inclos'd
Air, the Fibres, of which the Cylinder MN consists, are agitated
more also, and a greater Agitation is communicated to the outward
Air.
2352. If, the compressing Weight remaining the same, the Density be en-
2109. creas'd, the Matter mov'd is indeed encreas'd in the same Ratio with
the encreas'd Density ; but we demonstrate in the second Scholium,
annexed to this Chapter, that *the Intensity of Sound*, in this Case,
is diminish'd in the Ratio, in which the square Root of the Density
2353. encreases. From whence it follows, that in Summer, *cæteris pari-*
bus, the Intensity of Sound is greater than in Winter.

EXPERIMENT 7.

2354. Suspend the Bell A in the Glass R ; and, when the Cock is open'd,
Pl. 76. F. 2 let the Air in the Glass communicate with the outward Air. Shake
I the

the Glafs, and obferve the Diftance, at which the Sound can be heard. The Glafs being heated together with the internal Air, and the Experiment being repeated, the Sound will be heard at a greater Diftance.

Thefe Things are fo, as long as the Temper of the Air remains the fame ; but this is often chang'd *. *Watery Vapours hinder the Intenſity of Sound very much.* 2355. 2117.2122.

There is alfo a Diftance of Sound ariſing from the Number of the Vibrations of the Fibres of the ſonorous Body ; that is, from the Number of the Waves produc'd in the Air in a certain Time ; for according to the different Numbers of the Percuſſions againſt the Ear, the Mind receives a different Senſation. 2356.

A muſical Tone depends upon this Number of Vibrations, which is ſaid to be ſo much the more acute, as the Returns in the Air are more frequent, and the more grave, the leſs the Number of Waves is. 2357.

And the Degrees of the Sharpneſs of different Tones, are to one another as the Number of the Waves, which are produc'd in the Air at the ſame Time. 2358.

*A Tone does not depend upon the Intenſity of the Sound ; and an agitated String gives the ſame Sound, whether it goes and comes along a greater, or leſs Space *.* 2359. * 1292.2357.

Concords ariſe from the Agreement between the different Motions in the Air, which affect the auditory Nerves at the ſame Time. 2360.

If two tremulous Bodies perform their Vibrations in the ſame Time, there will be no Difference between the Tones ; and this Agreement, which is the moſt perfect of all, is call'd an Unifon. 2361.

If the Vibrations be as One to Two, this Concord is call'd an Octave or Diapaſon. 2362.

If they be as Two is to Three, that is, if the Second Vibration of one Body always agrees with the third of another, ſuch a Concord is call'd a Fifth or Diapente. 2363.

Vibrations which are as Three is to Four, produce a Concord call'd a Fourth or Diateſſeron. 2364.

A Ditone is when the Returns of the Air are as Four is to Five. And a Sesquiditone is a Concord ariſing from the Concurrence of the fifth Vibration of one Body with the Sixth of another. 2365. 2366.

Concords produc'd from the Agitations of Strings, if they be of the ſame Kind, are eaſily determin'd from their Dimenſions and Tenſion ; for the Agitations of the ſmall Parts do depend upon the Agitations of the whole Strings. 2367.

2368. *Cæteris paribus*, if the Lengths of two Strings be to one another as the Number of Returns in a Concord, the Concord or Consonance between the Sounds, which the Strings produce, will be had *.
- * 1294. The same will happen, if, *cæteris paribus*, the Diameters have the
2369. *aforsaid Proportion* *.
- * 1295. Also if, *cæteris paribus*, the Proportion of the Vibrations in a Con-
2370. cord be given between the square Roots of the Tensions *.
- * 1293. And generally, supposing any Strings of the same Kind, if the Ra-
2371. tio compounded of the direct Ratio of the Lengths, and that of the Diameters, and of the inverse Ratio of the square Roots of the Tensions, be the Ratio between the Numbers of the Vibrations perform'd in the same Time in any Consonance whatever, you will have that Conso-
- * 1296. nance by the Agitation of these Strings *.

Musicians have confirm'd all these Things by Experiments.

They have observ'd a very notable phenomenon about these Strings, whose different Cases are well worth explaining.

2372. Let any musical Strings be so stretch'd as to perform their Vibrations in the same Time; if one of them be agitated, the other will be mov'd also. For every Wave of the Air arising from the tremulous Motion of the first String, strikes the second String, and communicates a small Motion to it; and it goes backwards and forwards several Times, from the least Motion *, being mov'd by the Stroke of the first Wave, whilst the second Wave comes forwards, whose
- * 1292. Motion conspires with the Motion of the String *; and accelerates it. What is said of the second Wave is true of the other Waves which follow, and there will be an Acceleration till the Motions of the Strings be nearly equal.

2373. It follows from the same Demonstration, that the String mov'd communicates Motion to the other, which performs two or three Vibrations whilst the first performs one.

2374. And if the agitated String performs various Vibrations, whilst the String which is to be mov'd by the Air can perform only one, it will follow from the Demonstration foregoing, that it must communicate a particular Motion to it: To find out which, it must be observ'd, that the Duration of the Vibration, and the Length of the String are reciprocal in such Sort, that every Thing else continuing as before, the determin'd Length can no Way be separated from the determinate Duration of the Vibration. If therefore any String be struck with several Strokes, by which Motion is communicated to it, and the Strokes are more frequent than what is agreeable to the Length of the String, that Part of it whose Length agrees with the

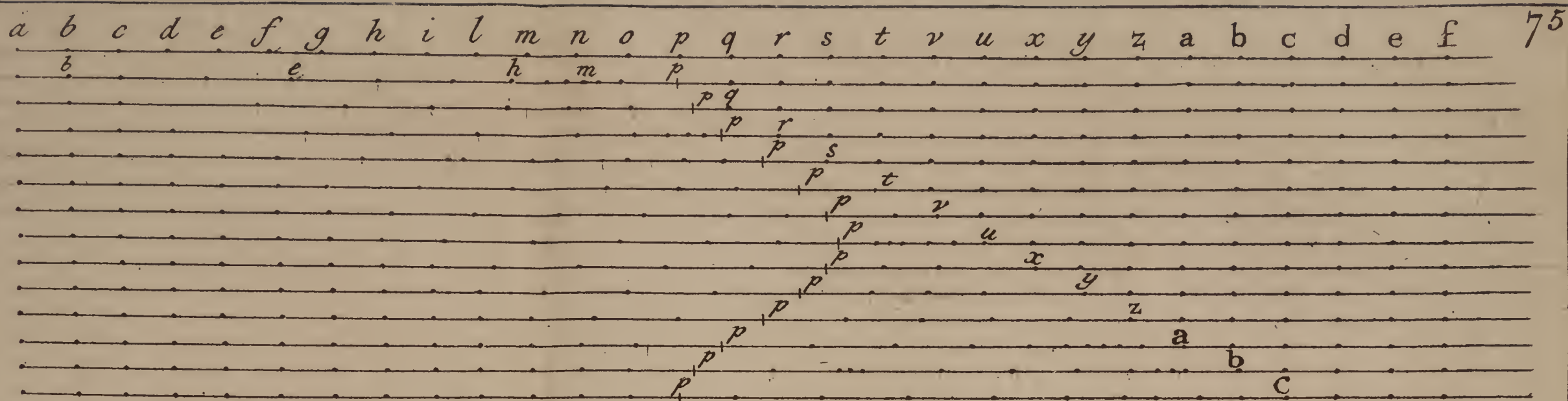


Fig. 1.

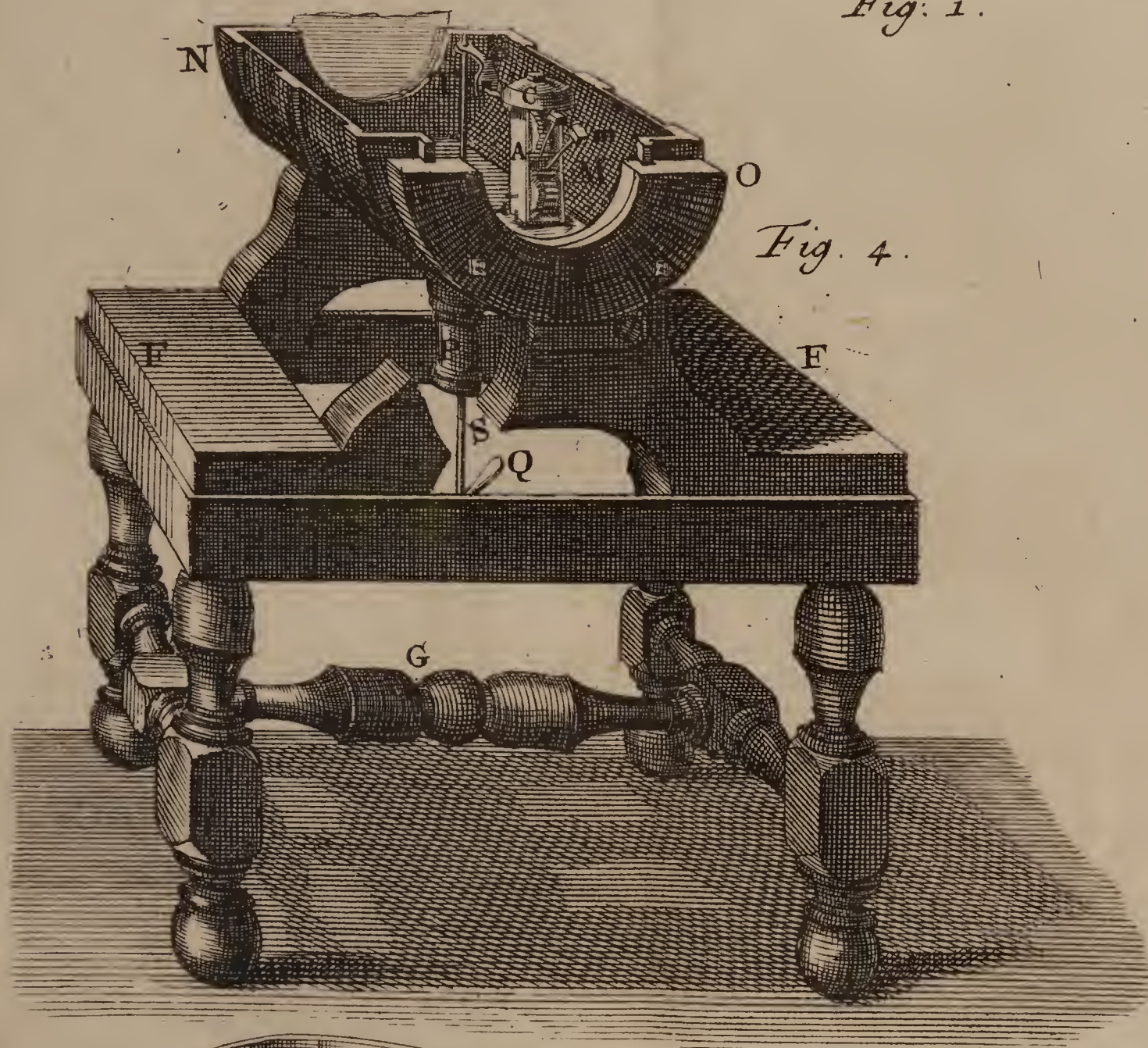


Fig. 4.

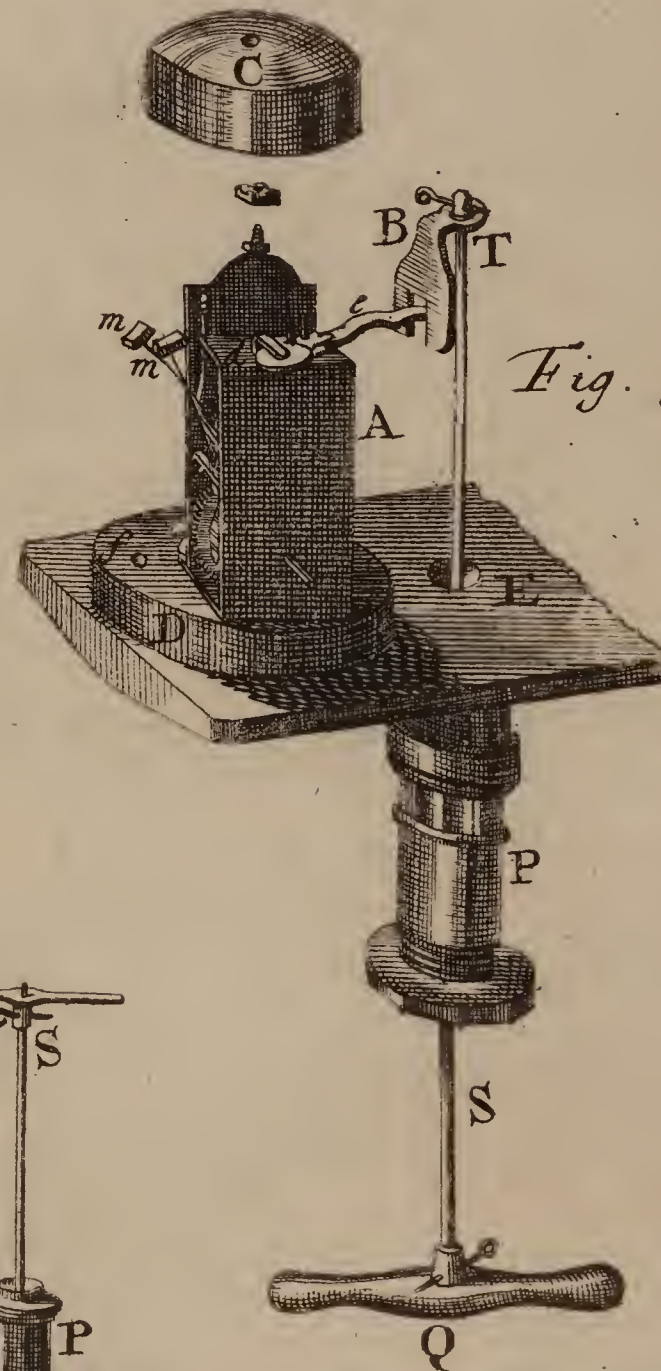


Fig. 5.

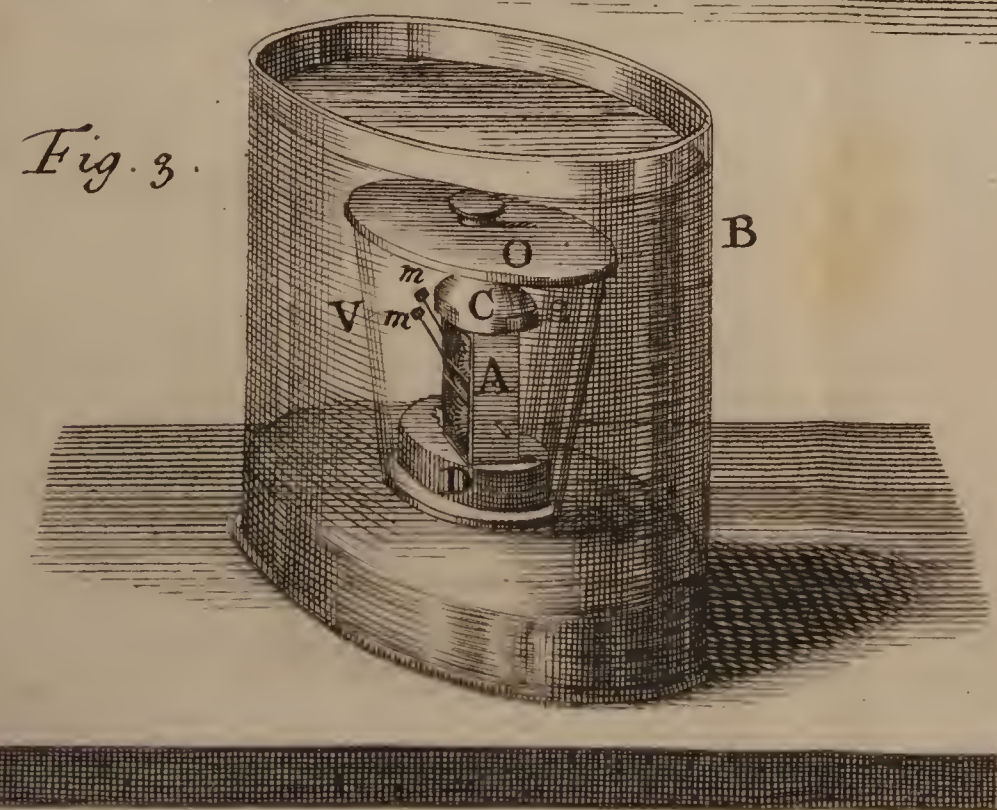


Fig. 3.

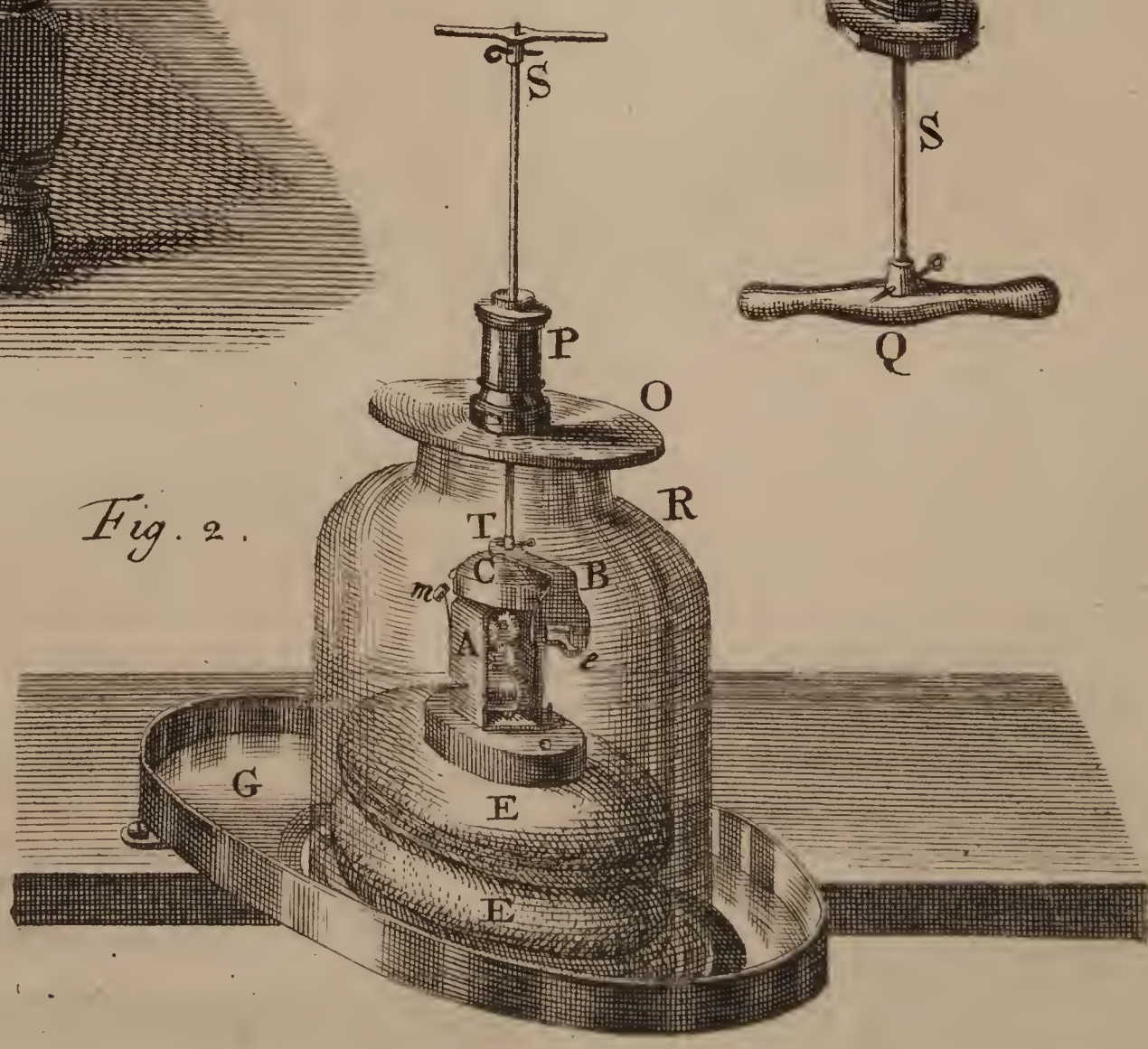


Fig. 2.

Handwritten text at the top of the page, possibly a title or header, which is mostly illegible due to fading.



the Duration of the communicated Vibrations, will be agitated only, and there will be a Sort of undulatory Motion communicated to the String; and the Length of the Waves in the String will depend upon the Duration of the Vibration that is communicated, that is, upon the Time between the Strokes.

*Let there be two Strings, the one of which vibrates twice whilst the other vibrates once, and let the first String be put in Motion, the Duration of the Vibrations communicated to that String by the Motion of the Air, agrees to a String of half it's Length *, and * 2375. 1294. such is the Length of the Waves in it. Therefore the String is divided into two equal Parts by the communicated Motion, and the middle Point is at Rest. This is confirm'd by an Experiment, viz. laying a Piece of Paper upon a String, to which the Motion is communicated; for if it be put upon the middle Point of the String it will be at Rest, though in every other Place it will be affected with a tremulous Motion.*

If one String which is put in Motion in order to cause Motion in another, performs three Vibrations whilst the String to be mov'd performs but one, this last will be divided into three Parts by the Motion communicated, and there will be two Points of Rest; which is likewise confirm'd by an Experiment like that above-mention'd. All other Cases of communicated Motion, which Musicians have observ'd, are easily deduc'd from what has been said.

What has been said of the Reflection and Inflection of the Waves in Water *, may be refer'd to the Reflection of the Waves in the Air; the Elasticity in this Case producing the same Effect as the Pressure of the rais'd Water in that. * 2377. 1742. 1744. 1745. 1746.

*From the Reflection of Sound there often arises a Repetition of it, which is call'd an Echo. If the several Parts of the same Wave, expanding itself spherically *, strike upon different Surfaces, so that being reflected they meet, the Motion of the Air will be stronger there, and the Sound will be heard. The same Sound is often repeated several Times, from the different Parts of the same Wave reflected to different Distances, some of which also successively meet in the same Place. Sometimes we have such a Repetition from the Repetition of Reflection.*

Sound is increas'd by Reflection in a Tube, as we find in speaking Trumpets. The most perfect Figure that these Tubes can have, is that generated by the Rotation of a Parabola about a Line parallel to the Axis, at the Distance of a Quarter of an Inch. For if any Body speaks in such a Tube, putting his Mouth in the Axis

of the Tube, and in the Forces of the Parabola, the Waves will be so reflected, that every one of their Parts will acquire a Motion parallel to the Axis of the Tube ; by which Means the Force of the Wave, and that of the Sound too, will be very much increas'd. The greater End of the Tube, from which the Sound goes out, must be bent so as to have the Shape of one's Lips, that thereby the Wave may more easily be scatter'd every Way.

EXPERIMENT 8.

2381.
Pl. 76. F. 3. Let a Person speak in a low Voice, applying his Mouth to the smaller Aperture of the Tube before-mention'd ; if the Tube be four Foot long, the Sound will be heard at a great Distance, and it will be very much increas'd in the neighbouring Places.

2382. The longer the Tube is, the more intense will be the Sound, and at the greater Distance will it be heard. There will also be a Difference, if, the Length continuing the same, the Tube be wider, like A, or narrower, like B. I have not determin'd by Experiments, through which of these Tubes, the Sound may be convey'd to the greater Distance.

SCHOLIUM I.

The Demonstrations of N. 1150. 1152.

2383.
* 2291. **I**N order to make manifest, what has been said concerning the Law, to which Particles, having an undulatory Motion, are subject, in going and coming *, we must consider ; that the Law of Elasticity determines the Motion of the Air, and that, *vice versâ*, the Law of Elasticity may be determin'd, from that Motion being given.

I shall take this last Method ; and supposing all the Particles, in going and coming, to be mov'd, like a Body vibrating in a Cycloid, that is, to be press'd with a Force, which is increas'd and diminish'd, with the Distance from the middle Point of the Space, run through in going and coming *, I shall demonstrate that that very Law of Elasticity, which we found before to obtain in Air *, is requisite to produce this : Whence it will appear, that the Particles of the Air do really move according to the Law of a Pendulum vibrating in a Cycloid.

2384.
Pl. 76. F. 4. Let there be a Circle AFB, whose Circumference is equal to the Breadth of a Wave ; let there be a smaller Circle, GIOL, concentric with the former, whose Diameter is equal to the Space, run through by the Particles, in going and coming ; which as it is small, this Circle is of no sensible Magnitude in respect of the other.

Let

Let us suppose the Circumference of the smaller Circle to represent the Time, in which the Wave runs through it's Breadth ; that is, the Time in which a Particle goes and comes * ; and therefore it runs through the Line GO twice, according to the Law of a Body mov'd in a Cycloid by Gravity : Therefore half of the Circle represents the Time, in which this Line is run through once. * 2284.

In the greater Circle, let EF be the Distance between the Centers of two neighbouring Particles at Rest ; Lines being drawn from E and F to the Center, the Arch I*i*, in the smaller Circle, will represent one of the Moments, mention'd N. 2285 : For we suppos'd the greater Circumference to be equal to the Breadth of the Wave.

Therefore, if a Particle be carried through GH, the next Particle that follows it, which was mov'd one Moment longer, will be carried through G*b* *, IH, *i**b*, being drawn Perpendicular to GO ; and the Difference of their Translations will be H*b* ; but the Difference of the Motions of neighbouring Particles, is the Increase, or Diminution, of the Distance between them : In this Case, in which the antecedent Particle was carried through a less Space, H*b*, or I*m*, which we suppose parallel to it, is the Diminution of the Distance ; which itself is therefore EF Minus I*m*. * 467.

The Ratio between I*m* and EF is compounded of the Ratio of I*m* to I*i*, and of I*i* to EF. The first Ratio is that which is between IH and IC ; by Reason of the similar Right-angled Triangles I*m**i*, IHC. The second Ratio is that, which is between IC and CE, as is manifest. The Ratio compounded of these is that of IH to EC, or AC.

Therefore, if we denote the Distance between the Particles, before the Agitation, by the Semidiameter of the greater Circle, HI will represent the Diminution of the Distance, whilst the Arch GI represents the Time of the Agitation *. By a like Demonstration it appears, in the return of the Particles, that HL represents the Increase of the Distance, if the Arch OL represents the Time of the Return, that is, the Arch GIOL the Time of the Agitation. * 467.

Now if we suppose a Line PQ, parallel to GO, and which touches the greater Circle at P ; and if HI be continued to R ; HR will be equal to AC, taking away HI there remains IR, which denotes the Distance of the Particle from the neighbouring one, supposing GI to be the Time of the Agitation, if this were GIOL the Distance between the Particles wou'd be RL ; and the Distances, in any Moments whatsoever, are represented by Lines parallel to the Line PC, terminated on one Side by the Line QPS and on the other by the Semicircle GIO in going, and OLG in coming.

The Difference between two neighbouring Distances is *i**m* or *u**l*, if I*i*, or L*l*, as before, represents the Moment, mention'd in N. 2285. in which Case these last small Lines are constant : But as we suppose the Particles to be mov'd, in going and coming, according to the Law of a Pendulum, vibrating in a Cycloid by Gravity, the small Lines as *i**m* or *u**l*, if I*i* or L*l* be constant, represent the Force accelerating the Motion, whilst

* 468. whilst the Time of the Agitation is represented by GI, or GIOL * :
 2385. Therefore *the accelerating Force, which, every Moment, acts upon every one of the Particles, in the Motion which we have suppos'd, is proportional to the Difference between the neighbouring Distances of the Particles*; namely if this accelerating Force agrees with Gravity in this, *viz.* in acting upon a Particle in Motion, as it wou'd act upon one at Rest *; which will happen, if the accelerating Force depends upon the Elasticity of the Air; for then the moving Cause is transfer'd with the Particles themselves.

2386. But we demonstrate that this very accelerating Force does really take Place in the Air. The Force, with which the Particles, whose Distance is represented by IR, mutually repel one another, is to the Force with which the Particles are repelled from one another, whose Distance is ex-

* 2111. pressed by ir as $\frac{I}{RI}$ to $\frac{I}{ri}$ *; and the Difference of these Forces is the Force, with which the middle Particle is agitated; which Force is expressed by $\frac{I}{ri} - \frac{I}{RI} \propto \frac{RI - ri}{RI \times ri} \propto \frac{mi}{RI \times ri}$; whilst the Force, with which the Particles at Rest mutually fly from each other, whose Distance is represented GQ, is $\frac{I}{GQ}$.

Therefore these Forces are as $\frac{mi}{RI \times ri}$ to $\frac{I}{GQ}$, or as $mi \times GQ$ to $RI \times ri$, or to GQ^2 ; because, as the less Circle is of no sensible Magnitude, in respect of the greater, QG, RI, ri , may be looked upon as equal, without any sensible Error. Therefore the last Ratio mentioned is that which is between mi and GQ; namely by dividing each Quantity by GQ, which does not alter the Ratio between them. If therefore we represent by GQ the Force, with which the Particles at Rest mutually fly from one another, im , that is, the Difference of the neighbouring Distances, will express the accelerating Force; which is that, which is required, that every one of the Particles may move according to the Law of a Body vibrating in a Cycloid *. Which was to be demonstrated.

* 2385. The accelerating Force, which acts upon the Particles of Air, may be compared with Gravity, and the Celerity of a Wave with the Celerity of a falling Body, as was said in N°. 2293.

2387. When a Body vibrating in a Cycloid, runs through this whole Curve, it is pressed with it's whole Weight in the Points, which are most remote from the middle Point of the Way to be run through *; therefore, in order to compare with Gravity the Force accelerating the Motion of the Particle, whilst it goes and comes along GO, we ought to compare with the Weight of the Particle the Force, which acts upon it at G, or O, and presses it towards C.

* 412. 458. The Lines as Ii and im are confus'd in the Point G; therefore putting AD and EF equal, that is, putting AD equal to the Distance between the Particles at Rest, and drawing DC to the Center, Gg, which is equal to

to Ii , will express the Force, which at G presses the Particle towards C , whilst GQ expresses the Force, with which the Particles at Rest mutually repel one another *.

* 2386.

Let us suppose the Atmosphere, whilst the Quantity of the Air remains the same, to be every where above the Place, in which the Wave moves, of the same Density with the Air in this Place; and in this Case let the Height of the Atmosphere be SV ; let Ss be equal to AD , the Distance between the Centers of two neighbouring Particles; Ss is to SV , as Unity is to the Number of Particles in sV ; that is, Ss is to SV , as the Weight of one Particle to the Weight, with which the Particles S, s , are mutually driven towards one another; which Weight is equal to the Force, with which these Particles endeavour to recede mutually from one another by their Elasticity *.

* 361.

But the Weight of one Particle is to the Force at G , of which we have just spoken, in a Ratio compounded of the Weight of one Particle to the elastic Force of the Air at Rest, and of this elastic Force to the Force at G ; that is, in a Ratio compounded of that of Ss to SV , and QG to Gg . This last Ratio is compounded of the Ratio of QG , or AC , to GC , and GC to Gg , which is the same as the Ratio of AC to AD or Ss . Therefore the Ratio compounded of the Ratios of Ss to SV , and QG to Gg , is also compounded of the Ratios of Ss to SV , AC to GC , and AC to Ss ; which is the Ratio of $Ss \times AC \times AC$ to $SV \times GC \times Ss$, or of AC^2 , to $SV \times GC$; therefore the Force of Gravity and the Force, with which the Particles are agitated in the undulatory Motion are in this Ratio; and if a Pendulum, of the Length CG , should be moved with this Force, instead of Gravity, it would perform two Vibrations, in the Time, in which the Wave runs through it's Breadth; for in this Time a Particle goes and comes *.

* 2284.

Therefore if there be another Pendulum moved by the Force of Gravity and of the Length SV , the Square of the Time, in which this would perform two Vibrations, is to the Square of the Time, in which the Wave runs through it's Breadth, in a Ratio compounded of the direct Ratio of SV to GC , and the inverse Ratio of AC^2 to $SV \times GC$ *, of which is compounded the Ratio of SV^2 to AC^2 . Therefore the Times themselves are as SV to AC . But the Time, in which the Pendulum, whose Length is SV , performs two Vibrations, is equal to the Time, in which a Body, with a Celerity, acquired in falling half the Height SV , can run through the Circumference of a Circle, whose Semi-diameter is SV *; which Time as it is to the Time, in which the Wave runs through it's Breadth, that is, the Circumference of a Circle, whose Semidiameter is AC , as SV is to AC , in which Ratio are the Circumferences themselves, the Spaces run through are the Times; therefore the Velocities are equal *, and the Proposition delivered in N. 2293. is manifest.

* 433.

* 376. 415.

* 120.

S C H O L I U M II.

Of the Intensity of Sound.

2388.

WE have seen that the Intensity of Sound follows the Ratio compounded, of the Ratio of the Number of Particles, striking against the Ear, in a certain Time, and the Ratio of the Square of the Velocity with which they strike against it *. These Ratios must now be determined.

* 2347.

The Number of Particles follows the Ratio of the Density of the Air ; as also the Ratio of the Velocity of the Wave ; for the swifter this is, the shorter is the Time in which the same Number of Particles acts upon the Ear, and the greater is the Number of the Particles acting at the same Time. The Number of these Particles also follows the Ratio of the Space, run through by the Particles in going and coming ; for the greater the Space is, the more the Particles remote from the Drum of the Ear run against it. Lastly this Number follows the inverse Ratio of the Breadth of the Wave ; because the Percussions of the same Particles are the less frequent, the broader the Waves are.

The Square of the Velocity, with which all the Particles act, follows the Ratio of the Square of the Velocity of the Wave. Of the Square of the Space run through, in going and coming. Lastly the inverse Ratio of the Square of the Breadth of the Wave.

2389.

When the Velocity of the Wave is not changed, the inverse Ratio of the Breadth of the Wave is the direct Ratio of the Number of Waves, running against the Ear in a determinate Time ; supposing equal Waves to follow one another, such as are the Waves, which are generated by the continued Agitation of a Fibre.

The Ratio compounded of all the Ratios mentioned is the Ratio compounded of the Ratio of the Density, the Ratio of the Cube of the Velocity, the Ratio of the Cube of the Space run through in going and coming, and the inverse Ratio of the Cube of the Breadth of the Wave.

If we set aside the Acceleration mentioned in N. 2305. (which does not alter the Velocity with which every one of the Particles is moved, which only is treated of here.) The Cube of the Velocity follows the sesquiplicate direct Ratio of the Elasticity and the sesquiplicate inverse Ratio of the Density *.

* 2298.

Therefore the two first Ratios mentioned are reduced to the sesquiplicate Ratio of the Elasticity, and the Inverse subduplicate Ratio of the Density. But the Elasticity is as the compressing Weight *, which follows the Ratio of the Height of the Mercury in the *Torricellian* Tube.

* 361.

2390.

Therefore in general, the Intensity of Sound is directly as the Square Root of the Cube of the Height of the Mercury in the Torricellian Tube, as the Cube of the Space run through in going and coming, and as the Cube of the Number of Waves, running against the Ear in a determinate Time, and inversely as the Square Root of the Density.

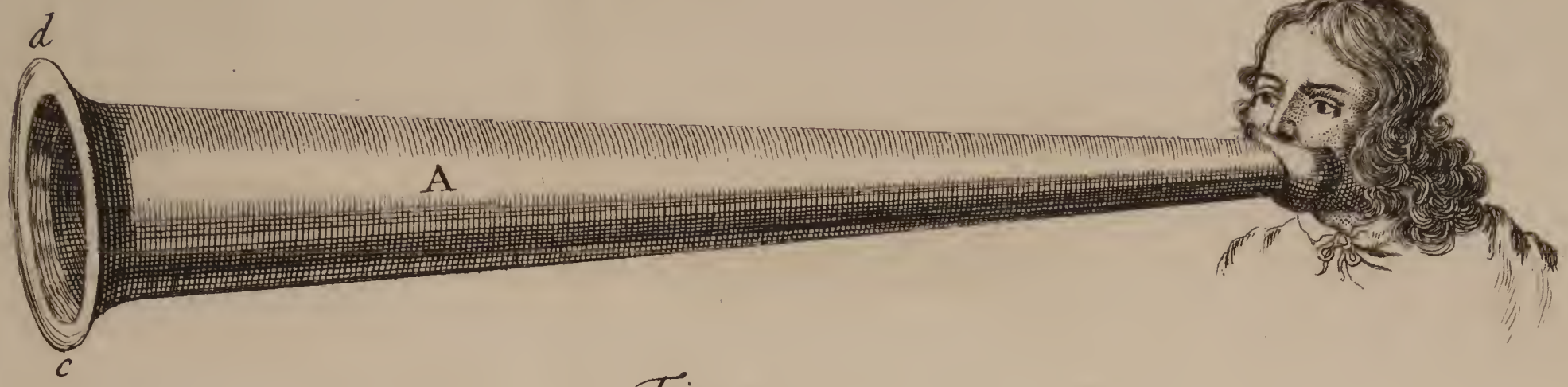


Fig. 3.

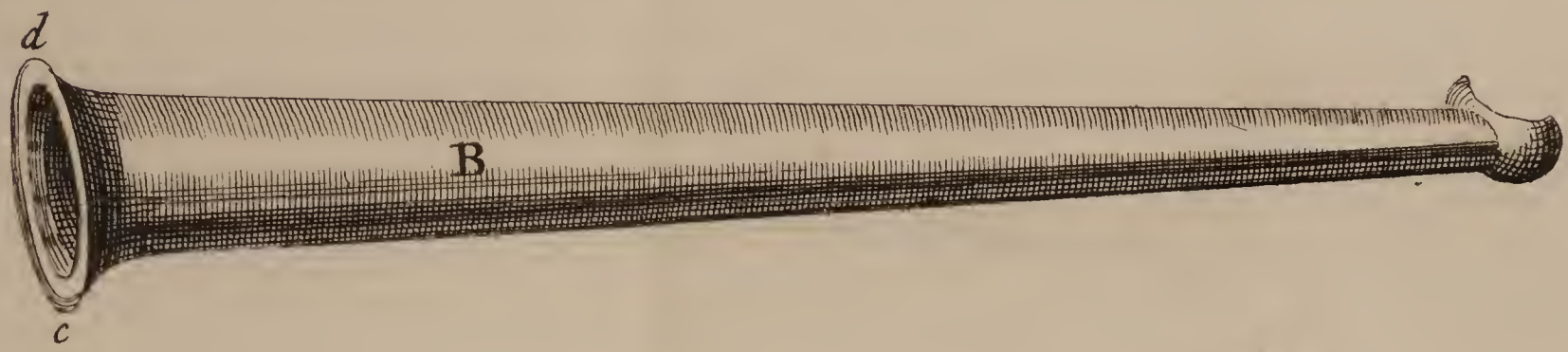


Fig. 1.

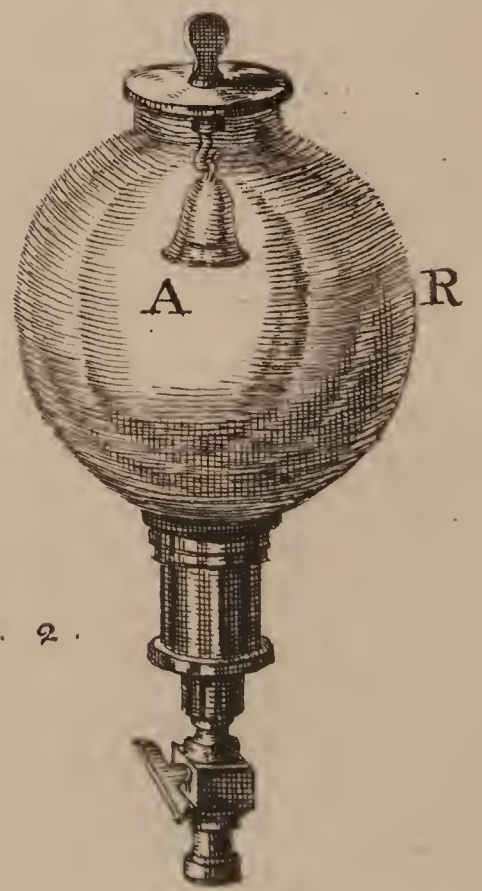
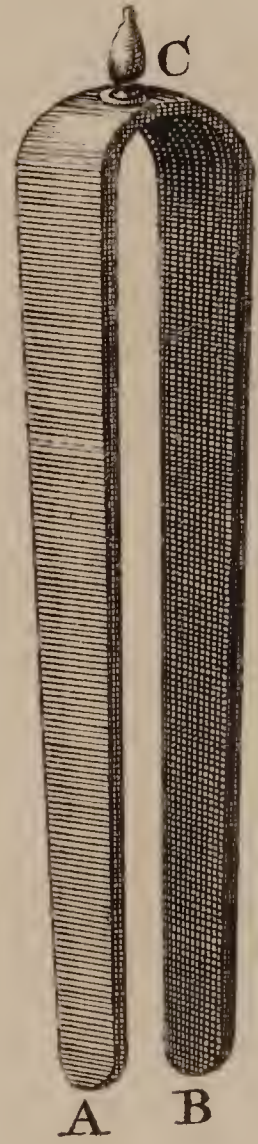


Fig. 2.

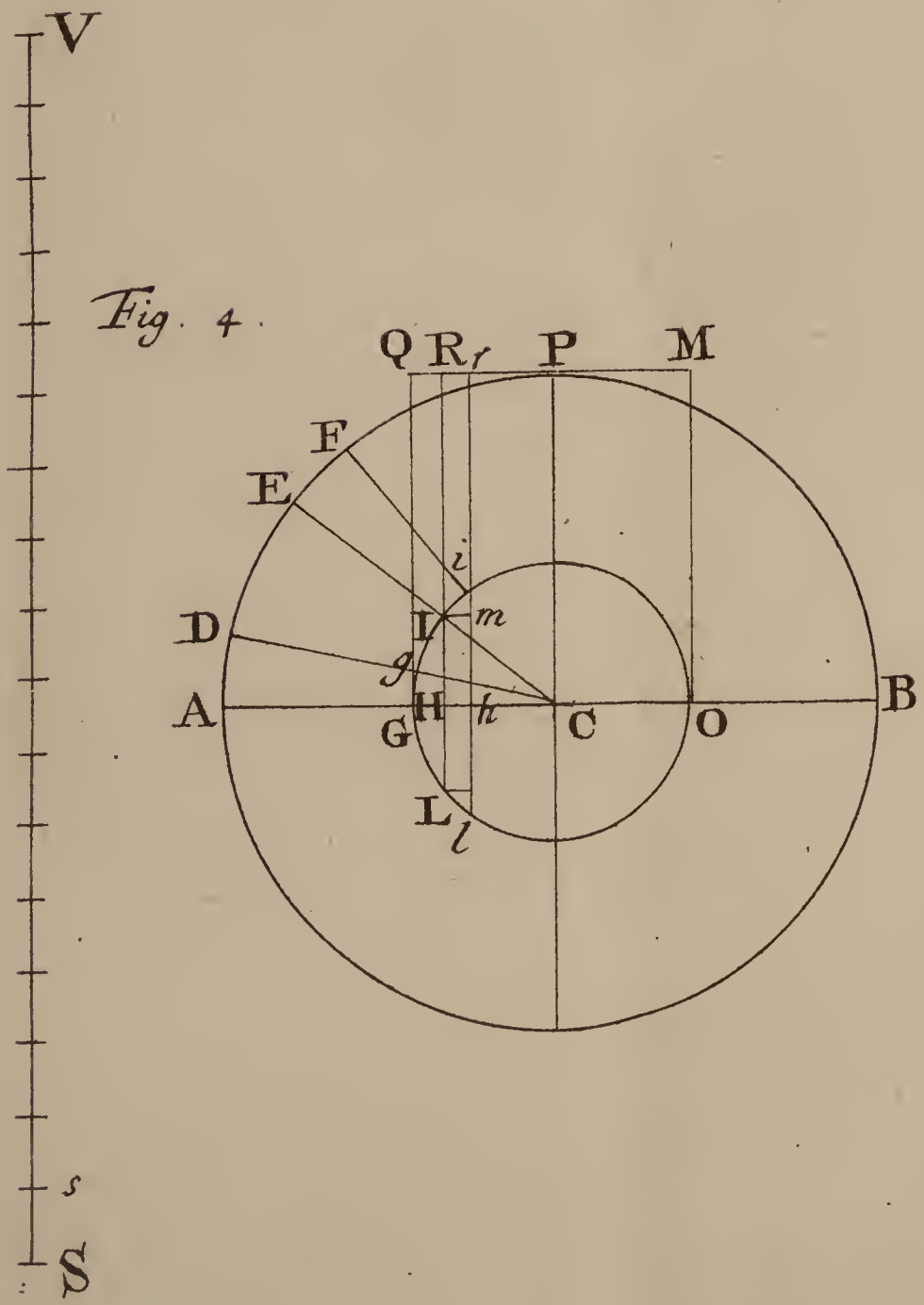


Fig. 4.

B O O K V.

PART II. OF FIRE.

C H A P. VIII.

Of the Properties of Fire in general.

THE Philosophers know a few Properties of Fire, yet many Things relating to it are conceal'd from them. I shall not invent Hypotheses, but shall lay together, in as good Order as I can, such general Things about it as appear to me to be deduc'd from Experiments. 2391.

The intimate Nature of Fire is unknown ; but wherever we find Heat and Light, we say that there is what we call Fire. 2392.

Therefore in order to inquire into the Properties of Fire, we must examine such Bodies wherein we discover one or the other of these Tokens of the Presence of Fire. 2393.

For we do not every where find both these together ; in several hot Bodies we can perceive no Light ; neither in several light Bodies can we discover any Heat. But whether there be really such a Separation, we shall examine hereafter *. 2394.

We shall also see, though perhaps it cannot be fully demonstrated, *that Heat and Light proceed from the same Cause*, which, notwithstanding, there is no Body can doubt. * 2418.

Fire penetrates into all Bodies, however dense and hard ; at the same Time also Heat is communicated into their inward Parts. 2395.

Fire unites itself to Bodies ; for that which stays in the Surface, is also transfer'd with the Bodies. 2396.

We shall see also that *Fire is attracted by Bodies at a certain Distance.* 2397.

Moreover, *we have no Knowledge of any Bodies but what contain Fire in them.* 2398.

Yet *Fire does not enter into all Bodies with the same Ease ;* which is to be attributed to several Causes, not known. It appears by Experiments 2399.

Experiments that when the Density is increas'd the Heat is diminish'd, and the Ingress becomes more difficult.

2401. *The Fire contain'd within Bodies, is kept there by the Bodies that surround them.*

2402. That *Fire* moves appears from what we now demonstrate, and that *it's Motion is exceeding swift*, is manifest from that most violent Agitation which is caus'd in Bodies, by the Action of Fire.

2403. When the Heat of Bodies is increas'd, *the Bulk of them is increas'd* too; and therefore they are dilated or swell'd by the Action of Fire. But upon the Increase of the Dilatation there are often

2404. Parts separated from the Bodies, which mutually repelling one another by the Action of the Fire, *form an elastick Fluid*, into which whole Bodies are oftentimes turn'd by the Action of Fire.

2405. But if this Motion in Bodies, by which they are dilated, be increas'd, the Effect of it is chang'd; and the Parts of the fluid Bodies, not yet separated, are sensibly agitated with a very violent Motion; and the Parts of the solid Bodies, which are not so subtile, will be separated from the adjacent ones.

2406. Which Motions nevertheless are often to be attributed to the Action of subtile Particles moved by the Fire, and penetrating the Pores of the Bodies.

2407. For that *there are subtile Parts, distinct from Fire, which penetrate Bodies by the Action of Fire*, is evident from the Increase of the Weight of some Bodies by the Action of Fire: Since *Fire*

2408. *itself has no sensible Weight.*

C H A P. IX.

Some general Things concerning Heat and Light.

* 2393. **W**E have already observ'd * that Heat and Light are the Tokens of the Presence of Fire; we shall therefore often speak of them, and general Things relating to them must be taken Notice of first of all.

2409. *The Heat in a Body must be distinguished from the Heat which we feel*; for that is the Action of the Fire upon the Body, which is said to be hot, from whence the Parts of the Body receive a certain Motion, by which a Motion is communicated to some Parts of our Body, which is united with the Perception of the Heat.

Chap. 9. *of Natural Philosophy.*

65

But *Heat, with regard to us, is nothing else but that Perception* ; and all that is in the hot Body, is only the Motion arising from the Action of the Fire.

2410.

The Light which arises from Bodies moves in right Lines, and those Bodies from which it arises are call'd lucid Bodies.

2411.

When Light enters into our Eyes, it moves the small Fibres at the Bottom of the Eye ; by which Motion the Perception of Light is produc'd in our Mind ; and this Perception with regard to us is Light ; but in regard to Bodies, Light is that which they emit into our Eyes.

2412.

What has been observ'd in general concerning the Sensations *, must also be refer'd to Heat and Light.

2413.

* 2310.

That the Motion of Light is in right Lines, appears from it's being stopp'd by an Obstacle.

2414.

But that *such a Motion is not requir'd in Heat, and that the Fire which is mov'd in different Lines excites a greater Heat*, appears from the Augmentation of this, whilst the Parts of Bodies are subject to different Motions.

2415.

All hot Bodies do not shine, as we daily observe ; but we cannot conclude from thence that they have no Light. For very often a small Light, which we do not perceive, will be very sensible to other People ; this depending upon the Constitution of the Eyes. From whence it follows, that there may be Light, though not perceiv'd, because of the too small Quantity which the lucid Body emits.

2416.

In like Manner the Heat in a Body may be so lessen'd, as to be imperceptible to us ; for it often happens that a small Heat, which does not at all affect us at one Time, will do so very sensibly at another Time : And therefore we cannot affirm that no Heat is in lucid Bodies, because we do not observe any.

2417.

Therefore *it is uncertain whether Heat and Light can ever be separated.*

2418.

But that these are very often united, there is no Body doubts. But whether both Heat and Light are justly said to be the Tokens of the Presence of Fire, that is, whether we can ascribe to the same Cause these two different Phenomena, so as to entirely remove all Scruples, cannot be determin'd ; yet, notwithstanding, the two following Considerations seem to shew that there is a Possibility of determining this Question.

2419.

In the first Place, there are *many hot Bodies, which, when their Heat is encreas'd, do emit Light* ; and to do this there is only requir'd an

2420.

increase of the Heat; and upon the lessening of this the Light ceases. Red hot Iron emits Light, but when the Heat is diminish'd no Light can be perceiv'd. Smoak, as we shall see presently, is turn'd into Flame, when it's Heat is increas'd.

2421. Secondly, *In the Sun's Rays there is a very intimate Union between the Heat and Light.* Those Bodies which reflect a great Quantity of Light, grow hot but slowly; but those which a greater Quantity of Light penetrates into, acquire Heat faster; and whilst the Light penetrates the Body, it does not always communicate to it a sensible Light together with the Heat, which yet often happens.

2422. Many calcin'd Stones, after they have been expos'd to the Sun's Light, shine in the dark, which Light continually decreases, and at last disappears; but it is restor'd again by a new Action of the Sun's Rays, and that several Times. Which same Property has been observ'd in other Stones, without any Preparation; not only when they have been expos'd directly to the Rays of the Sun, but if they have only been for some Time expos'd to the Light of the Day, in a Place, to which the Sun's Rays do not come directly.

In all these the Light is not communicated without Heat; and in the Cases in which this is weak, the Light communicated is also weak; but in other Cases Bodies acquire Heat, without any sensible Light, by the same Action of the Sun's Light, let this be ever so vivid.

2423. But *in the Moon's Light*, which proceeds from the Sun, *there cannot by any Art be discover'd any Heat*; yet there is nothing to be gather'd from thence that Light and Heat are distinct. *The Sun's*
2424. *Light, reflected by the Moon, which comes to us, is very weak.*

When the Moon is view'd with a Telescope, some Particles appear more lucid than the rest of the Surface; but all those join'd make but a small Portion of the Surface illustrated. These more lucid Particles do *not* reflect all the Light, which comes to them; whence it appears that the Light, reflected from the other Parts of the Surface of the Moon, is very much diminish'd. If to this we add that a great Part of the Surface of the Moon appears obscure, it will be manifest, that the Moon reflects only a small Part of the Light, which comes to it from the Sun. This Light, thus already weaken'd, is dispers'd before it reaches us, whereby it is again diminish'd almost fifty thousand Times. Yet this very Light is perceiv'd by the wonderful Structure of our Eyes; if the Heat were lessen'd so much, who wou'd affirm that it ever *can produce any sensible Effect*?

C H A P. X.

Of the Dilatation arising from Heat.

WE have already said that Bodies are dilated by Heat * ; but * 2403.
 as this *Dilatation* always increases with the Heat, and this 2425.
 being lessened, is lessen'd, it *forms a new Token of the Presence of*
Fire, which is more certain than those mention'd before * ; for we * 2393.
 can measure the Dilatation, when at the same Time the various
 Perceptions of Light, or Heat, can scarcely be compar'd together.
 It is evident, by Experiments, that Bodies are dilated by Heat. 2426.

EXPERIMENT 1.

The Aperture of the Copper Ring AB is circular, and it's Dia- 2427.
 meter is an Inch and an half ; and this is the Diameter of the solid Pl.77.F.1.
 Ball G, which is made of the same Metal ; this can pass through
 the Aperture, without leaving any sensible Interstice. When the
 Globe is heated it is sustained by the Ring, in whatever Position
 it is laid ; which Experiment alone shews that Bodies dilate every
 Way.

It may be observ'd daily, that *Fluids are dilated by Heat, in the* 2428.
same Manner as Solids, in Thermometers, which are well known
 Instruments, made of Glafs.

Two such Instruments are represented at AG, and DC ; they Pl.77.F.2.
 are made of a Ball G, or better of a Cylinder C, with a Tube
 join'd to it, as AB, or DE ; they are fill'd with tinged Spirit of
 Wine, or some other Fluid, which does not lose it's Fluidity by
 Means of Cold.

EXPERIMENT 2.

A small Heat, communicated to the Ball, causes a sensible Ex- 2429.
 pansion in the Tube.

If we make Use of Mercury, the densest of Fluids, the Dilata- 2430.
 tion is more regular ; but the Tube must be narrower, because this
 Fluid dilates less.

These Instruments are applied to Frames, and the Dilatations 2431.
 are compar'd, by Means of Divisions dispos'd along the Tube.

But it is uncertain, whether these Instruments can shew the Degree 2432.
 of Heat, although they shew the smallest Alterations of Heat. That

is, the Relation between the Alteration in the Expansion and the Alteration in the Heat, is not enough known, that the Degrees of Heat may be compar'd together, from comparing the Dilatations.

2433. If the Ball G becomes hot on a sudden, or the Cylinder C, the Fluid immediately descends in the Tube ; but it ascends immediately after.

EXPERIMENT 3.

2434. Boiling Water is pour'd into the Vessel V ; the Ball G of the
Pl. 77. F. 3. Thermometer is immediately immerg'd into it ; and the Fluid that very Moment descends from *c* to *d* ; but it immediately returns to *e* and higher : Then if the Ball be not suddenly taken out of the Water, the Spirit of Wine will rise to the Top of the Tube, and break the Glass by it's greater Expansion.

2435. The Reason of this Phenomenon is as follows.

By the sudden Heat, applied to the Glass, it is dilated, before the Heat penetrates into the Fluid contain'd in the Glass ; therefore, the Fluid descends by Reason of the Increase of the Capacity of the Glass ; but the Heat is immediately communicated to the Fluid ; which therefore ascends.

2436. From the Expansion of Bodies it is evident, that *the Particles, of which Bodies consist, acquire a repellent Force from the Action of Fire, by which they endeavour to recede from one another*, and which acts contrary to that Force by which the Particles come towards

- * 72. each other *. So long as this last Force exceeds the other, the Particles cohere more or less, according to the different Degree of Heat. When the repellent Force is nearly equal to the attractive Force, the Particles, which were before intimately join'd, scarcely cohere, yield to any Impression, and are easily mov'd one amongst another, if this be not prevented by another Cause ; in this Case a
2437. *solid Body is chang'd into a Fluid by Heat* ; which we may observe of all Bodies that are melted by Heat, and return to their first State when the Heat is diminish'd.

2438. *It is a Question whether all Fluidity is not owing to Heat ? But this cannot be determin'd* ; because we know of no Body that is entirely without Fire in it. This is certain, that Heat is not only the Cause of the Fluidity in melted Metals, Wax, and such like Bodies ; but several Bodies, which are commonly reckon'd amongst
2439. Fluids, proceed only from Heat : Thus *Water is melted Ice* ; for when Part of the Heat of the Water is gone, it grows fixed.

Heat may be so increas'd, that in some Bodies the whole attracting Force of the Particles may be overcome by the repellent Force; in which Case the Particles fly from each other; that is, they acquire an elastick Force, which is like that, which the Particles of Air * have *; (which also is increas'd in the Air by Heat;) we observe this Effect in Smoke and Vapours. 2440. 2096.

EXPERIMENT 4.

Take an hollow Brass Ball E, of about four Inches Diameter, with an Handle M; this Ball has a Pipe T with a Hole of hardly the twentieth Part of an Inch. Let this Ball be heated, and the Air in it will expand itself *, and come out through the Pipe; then, immersing the Ball in cold Water, the Air will be again condensed by the Cold, and the Water will go into the Ball, by the Pressure of the Atmosphere upon it's Surface. 2441. Pl. 77. F. 4. *

If this Ball, thus partly fill'd with Water, be laid upon the Fire, the Moment that the Water is chang'd into Vapours, those Vapours will go out through T; but if the Heat be increas'd, so as to make the Water boil violently, the Vapours, compress'd in the upper Part of the Ball, will, by their Elasticity, endeavour to recede from each other every Way, and rush violently out of the Pipe. 2442.

Such an Instrument is call'd an *Æolipile*.

The following Experiment shews a more sensible Effect of the Elasticity of Vapours. 2443.

EXPERIMENT 5.

Take the Ball E, which is also of four Inches Diameter, made thicker than the Ball, made Use of in the foregoing Experiment, and let it be join'd to Rollers or little Wheels, as is represented in the Figure. In it's upper Part a square Box T, open forwards at a, is join'd to it. In the Middle of this Box there is a Separation, and the hind Cavity communicates with the Cavity of the Ball. This Separation has a Hole in the Middle of it of about $\frac{1}{8}$ of an Inch Diameter. This Hole is stop't up with a Copper Pin, which goes through two Holes, as L, in the Sides of the Box, and applies itself to the abovemention'd Separation, and as the Figure of the Pin is somewhat conical, if it be drove in with a Hammer, it will exactly stop the Hole. 2444. Pl. 17. F. 3.

Take this Ball off of the Rollers or little Wheels; then let it be heated, and in Part fill'd with Water, as in the foregoing Experiment. Let the Ball be again put upon the Fire, 'till the Water boils, 2445.

boils, then shut the Hole, and let the Ball remain upon the Fire a little while, that the Vapour may be accumulated. Now join the Ball to the Wheels, and open the Hole, and the Vapour will fly out violently one Way, whilst the Ball is carried the contrary Way.

2446. The Vapour, being very strongly compress'd, endeavours to recede equally every Way, and therefore opposite Pressures destroy one another; but when the Hole is open'd, the Vapour, which goes out, does not press; therefore the Pressure one Way being taken off, that which acts in a contrary Direction prevails, and the Ball is mov'd along.

2447. A Sky-Rocket rises up into the Air, because the Gun-powder, being set on Fire, is turn'd into an elastic Fluid, and it's Parts endeavour to recede every Way: As the Pipe, or Case of it is open at one End, it is less press'd that Way, and consequently at the other End, the Pressure prevails, and carries up the Rocket.

2448. *To the same Action of Fire, whereby Parts are separated by Means of Dilatation, we may also refer the Separation of Parts, which constitute the elastic Fluid, proceeding from Bodies, by Means*

* 2119. *of Putrefaction, Fermentation, and Effervescence* *. For this Separation is always accompanied with Increase of Heat, even in cold Effervescences themselves.

EXPERIMENT 6.

2449. To twelve Parts of Water add one Part of Oil of Vitriol; this Mixture acquires Heat, which lasts but a little while; then pour it into the Glass V, which is laid upon the Plate G of the Air-pump.

Pl. 77.
Fig. 5.

* 2152. To the same Plate we apply the small Brass Plate AB, which we fasten to the small Pipe, through which the Air is exhausted *, whose Screw goes through a Hole at B.

To this Plate is join'd the Cylinder C, which sustains another Plate L, which is also of Copper, and is so bent, as to be surrounded on one Side with a Groove *i*, making a Portion of a Circle, whose Center is in the Middle of the Hole *b*; this Groove is clos'd behind, as appears at *q*, and is fill'd with Sal Ammoniack, reduc'd to a Powder.

The Thermometer D is put into the Glass; this, together with it's Paper Scale, which is join'd to it, is inclos'd in a Glass Tube, and represented distinctly in Fig. 3. Pl. 81; there is also another Thermometer E made use of, which has a Stand. All these are cover'd with the Receiver R, which is clos'd with the Cover O.

To

Chap. II. *of Natural Philosophy.*

71

To the Cover is join'd the Collar of Leathers P *, whose Brafs Wire * 2155.
st, or ST, goes through the Hole *b*, and fits it exactly. To the
same Wire is join'd the Plate F, whose Part *n*, when the Wire is
push'd down, reaches to the Bottom of the Groove. But the
Wire is so dispos'd, that if, by turning the Handle, the Plate F
be agitated, it will not touch the Sal Ammoniack, which fills the
Groove ; but by depressing M, the Prominence *n* separates a Part
of the Sal Ammoniack in the fore Part of the Groove from the rest.

The Air is exhausted from the Receiver R, and by turning the 2450.
Handle M, the Sal Ammoniack, in the fore Part of the Groove, is
thrown into the Glas V. There is immediately caus'd a great Ef-
fervescence, which is increas'd, by separating some more Sal Am-
moniack in the Groove, and throwing it into the Glas again in the
same Manner as before.

During this Effervescence the following Observations are to be 2451.
made ; 1. That the Mercury in the Thermometer D is depress'd ;
whence it appears that the Effervescence is cold, though most of
them are hot. 2. That the Mercury in the mercurial Gage of the
Air-pump descends ; which demonstrates the Generation of an
elastic Fluid. 3. Lastly that we discover by the Thermometer E,
in which the Mercury ascends, that the Separation of Parts is made
with Heat.

We make the Experiments in a Vacuum, that the Phenomena
may be the more sensible.

C H A P. XI.

Of the Fire contain'd in Bodies, where we shall speak of Electricity.

WE have already said that Fire is contain'd in all Bodies 2452.
known to us *. And this we find to be so, because we * 2399.
every where find Fire ; for there are no solid Bodies round the
whole Surface of the Earth, but what may be made hot by rub-
bing ; but what is demonstrated in the following Chapter, does
more evidently prove, that there is Fire every where throughout
the Surface of the Earth ; viz. that Heat is communicated from a
Body which is hot, to another near it, which has not so much
Heat : From whence it follows, that if there be any without Fire,
and so without Heat, it will immediately receive Heat from the
neighbouring Bodies.

There are several very remarkable Phenomena, which are ascrib'd to the Fire contain'd in Bodies; some of which ought to be mention'd here: Amongst which there are such as have a near Relation to Electricity; for which Reason we must also treat of the Phenomena of Electricity.

DEFINITION.

2453. *Electricity is that Property of Bodies, by which when they are heated by Attrition, they attract and repel light Bodies at a sensible Distance.*

2454. Many Philosophers thought that very few Bodies had this Property; but it is now manifest that most Bodies have it, though unequally, and in a different Manner. Many surprising Things concerning this Property have been discovered in *England* and *France*; but to treat of this Matter wou'd lead us from our Purpose; I shall only mention a few Experiments, made above thirty Years ago in *England*, to make manifest the Connexion between the Cause of Electricity and Fire, if these two ought really to be distinguish'd; later Experiments confirm my Conclusions.

EXPERIMENT I.

2455. A Glass Tube 15 or 18 Inches long, and of above one Inch in Diameter is rubb'd with a dry Hand, or with a dry linen cloth, and Light is perceiv'd; this follows the Hand, and does not remain in the Tube itself, but, at a small Distance from it, in the Body, with which the Tube is rubb'd.

2456. When we cease to rub the Tube no Light is perceiv'd; but, if any Body be mov'd along the Tube a small Distance from it, not exceeding a Quarter of an Inch, a faint Noise is heard, and sparks of Fire emitted as it were out of the Glass with a Noise, appear upon the Surface of this Body. If the Body be again carried along the Tube, nothing of this is observ'd, without the Tube is first rubb'd again.

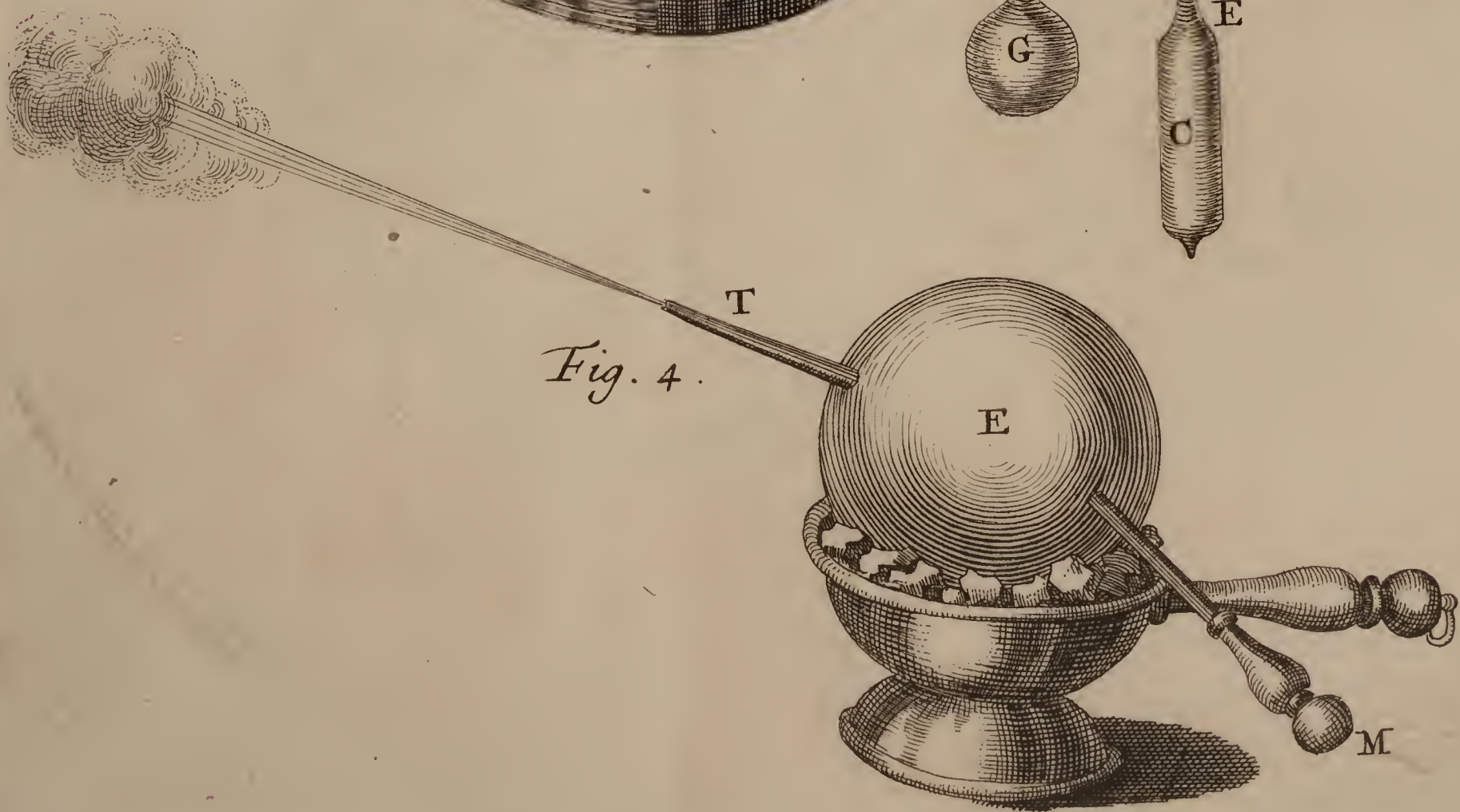
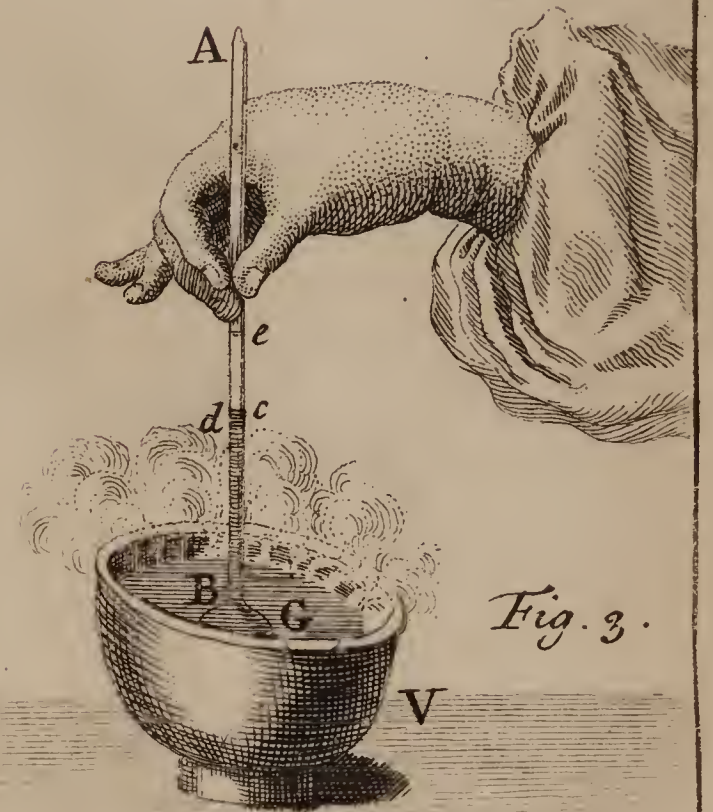
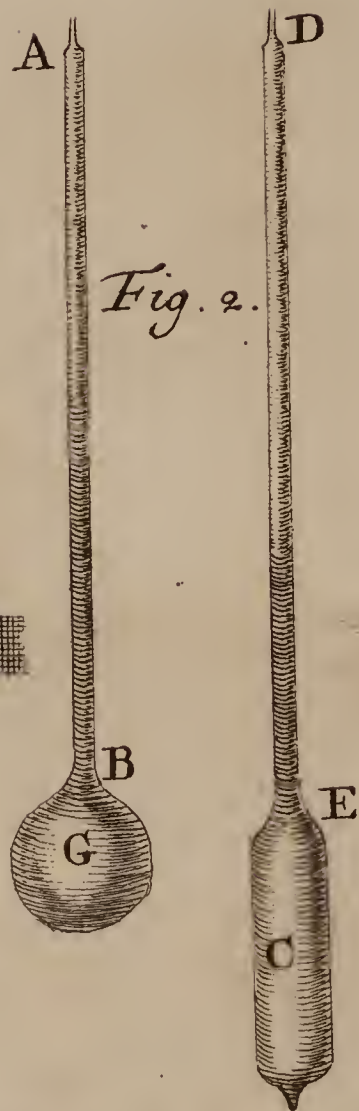
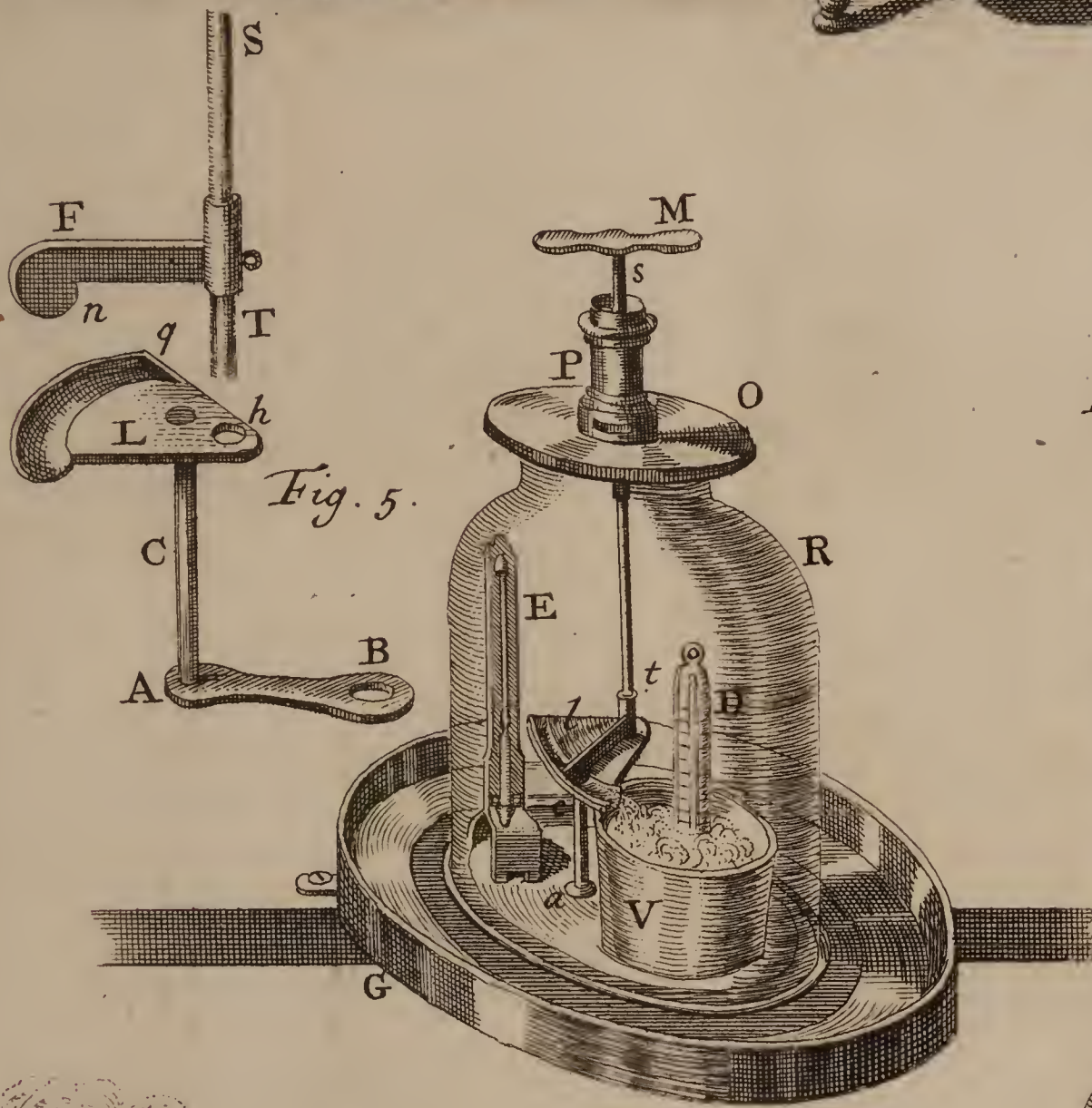
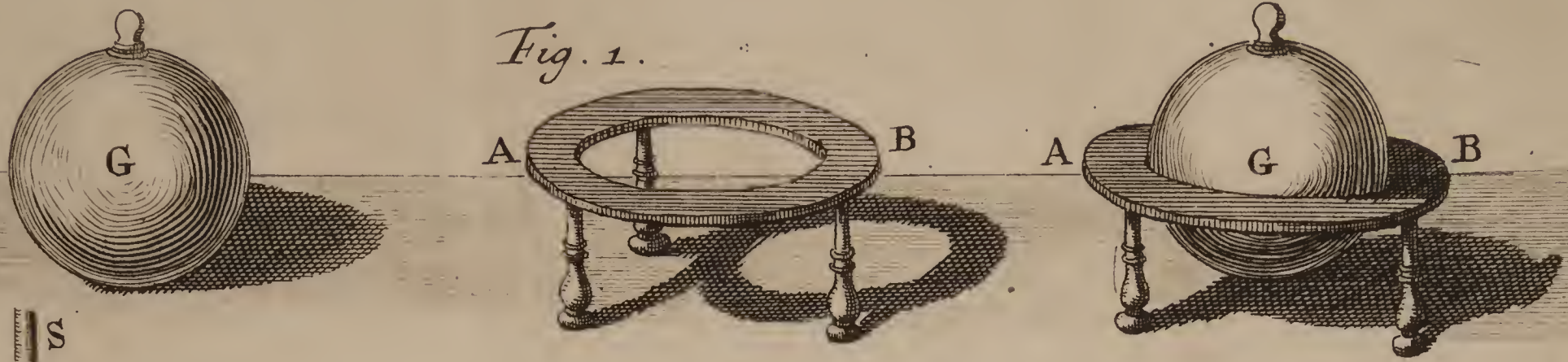
EXPERIMENT 2.

2457. This Tube by being rubb'd, acquires a very sensible Electricity; for if light Bodies, such as Leaf Gold and Soot, be laid upon a Plane, and the Tube be brought near to them, they will be put in Motion, attracted, and repell'd, and driven several Ways by the Tube.

Pl. 78.

Fig. 2.

Fig. 1.



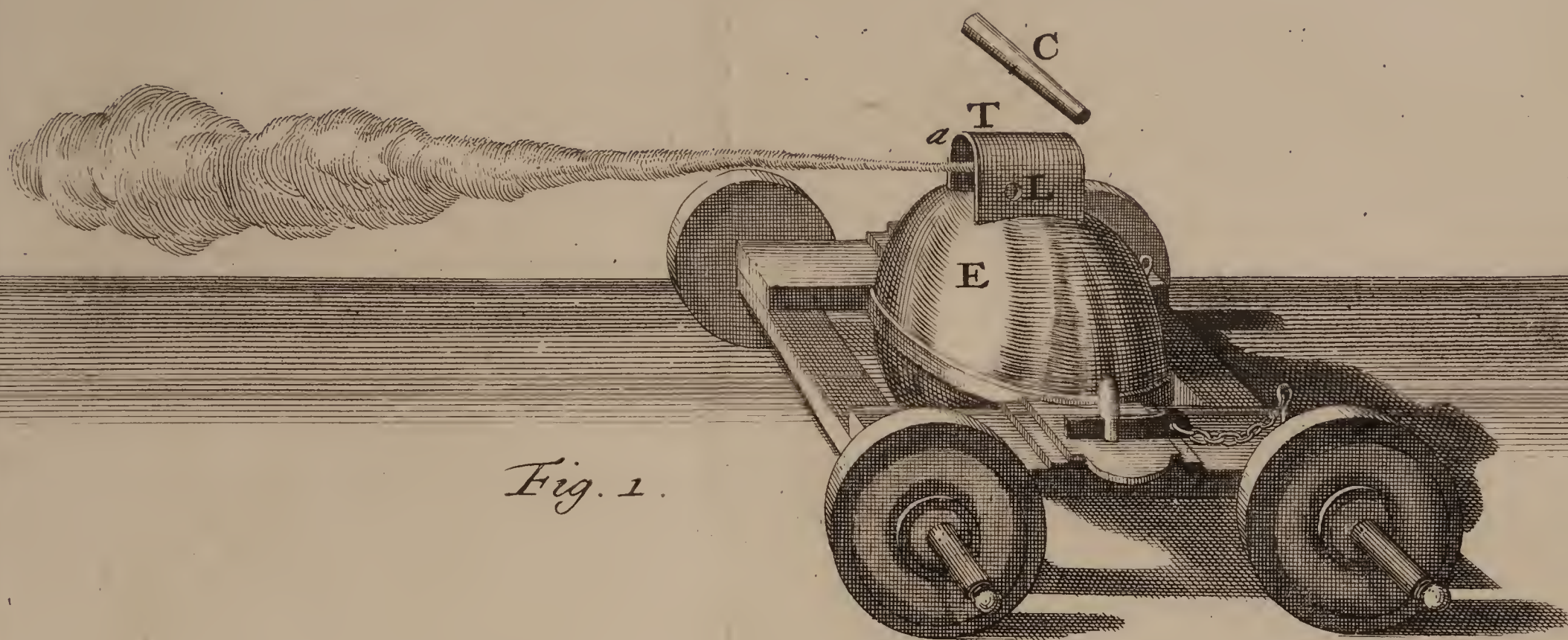


Fig. 1.

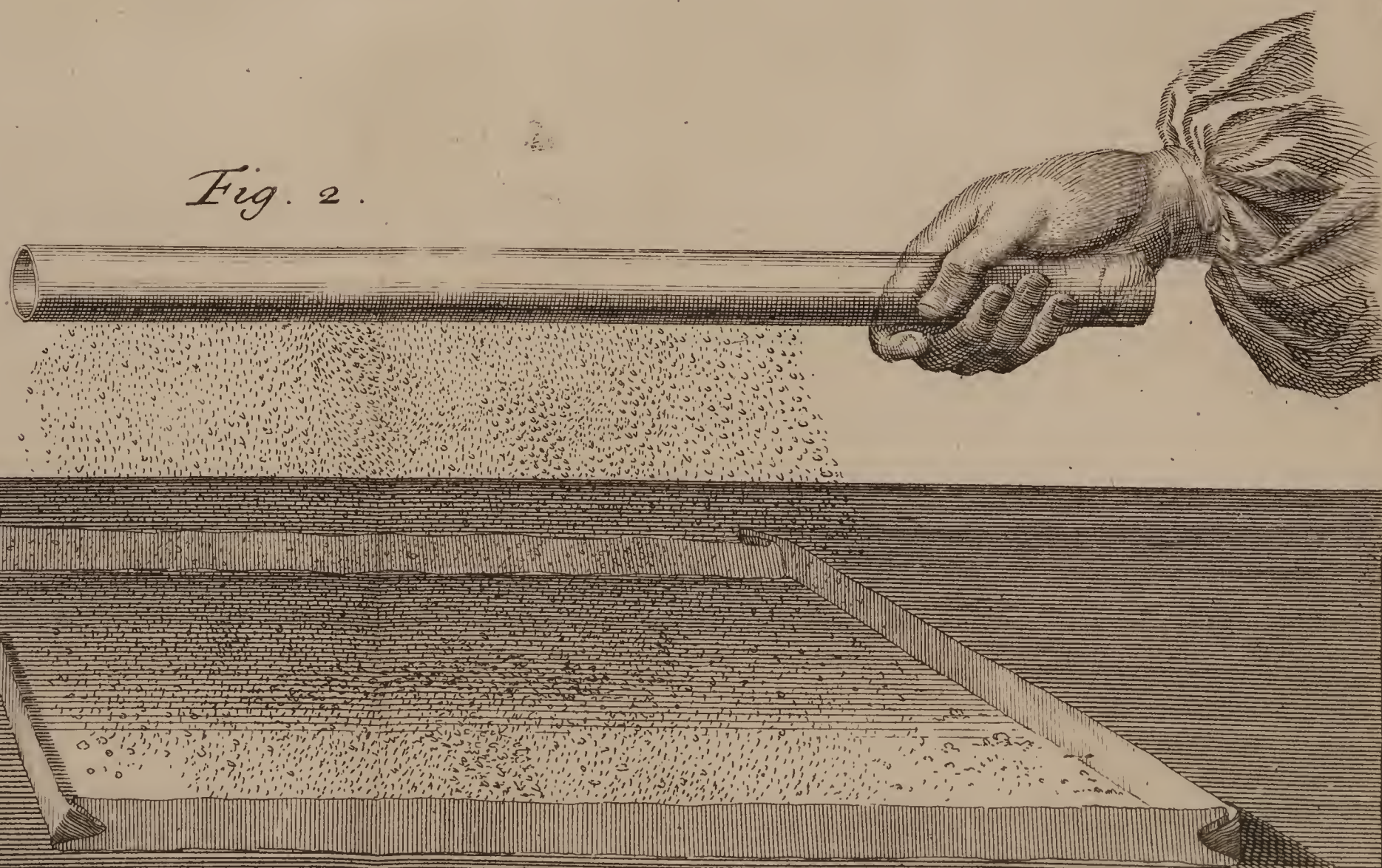


Fig. 2.

If a Body, at a small Distance from the Tube, be mov'd along it, a Noise is heard, as in the foregoing Experiment, and the Electricity ceases, which is restor'd again by Friction.

2458.

A M A C H I N E,

Whereby Glass Globes are swiftly whirl'd about.

In the following Experiments Glass Globes are swiftly whirl'd about. Such a Globe is represented at G; the two opposite Parts of it are cylindrical; one of which is open, and both these Prominences are surrounded with the Copper Ferrels *a* and *b*. A Cock *e* must be screw'd on to the Ferrel at the open Part of the Globe; and the opposite Brass Cylinder must have a little Wheel *r*, of about two Inches Diameter, join'd to it, with a small Brass Axis standing out; there is just such another Piece of Brass screw'd on to the Cock, so that it may be taken on and off at pleasure. These Axes go into the Pillars S T, that support the Globe, and which have the Holes *c*, *c*, in them, to receive the Axes, upon which the Globe turns.

2459.

Pl. 79. F. 1.

The Pillars S T stand upon a strong horizontal Board, at least an Inch and an half thick, framed into three other Boards E, F, I. Between the foremost is suspended the Wheel R, which is turn'd round by the Handle M. Between F and I is plac'd the cross Piece H, to make the Machine the firmer.

2460.

The Pillar S may be fastened in either of the three Places, *i*, *i*, *i*; the Tail of it, which has a Screw upon it, goes through the Board, that an outward Screw, which is screw'd on by a Key, may be join'd to it under the Board, a thin Plate of Iron being first put between, that the Wood may receive no Damage; which that it may be done conveniently, the Board E is cut at *l*, *l*, *l*. In the same Manner, the other Pillar T, which moves in a Slit, is fastened under the Board, by Means of a Screw; for this Motion is necessary, when the Globe is to be applied to the Machine or remov'd from it. This Slit is four or five Inches long; because the Globes, which we make Use of in the Experiments, are not all equal. There must be three such Slits, to answer to the Holes, *i*, *i*, *i*.

2461.

By the Wheel R the Globe G is swiftly whirl'd about; because the Rope, which goes round the Wheel R, goes also about the small Wheel *r*.

2462. At the Side of the Board D, there is a Slit at n , along which the Pulley t moves, as is represented separately at N; this Pulley coheres with the Screw d , by Means of which it is mov'd along the Slit, whereby the Rope is stretched that goes about the Wheels R and r , which Rope also goes about a Pulley fix'd under the Board, as is represented at M, the fix'd Pulley is q .

EXPERIMENT 3.

2463. Apply a Glas Globe of about eight or nine Inches Diameter, to Pl.79 F.2. the Machine above-mention'd, and let it be briskly whirl'd in a dark Place, the Hand all the while being held against it, to give it Attrition.

If the Globe be exhausted of it's Air, it will appear all luminous within, but mostly so where the Hand touches the Glas.

EXPERIMENT 4.

2464. But if the Globe has Air in it, and being whirl'd in the same Manner, the Hand be applied to it, no Light appears, either in the inner or outer Surface of the Glas; but Bodies at a small Distance from the Glas (as for Example at a Quarter of an Inch, or nearer) become luminous; and so only those Parts of the Hand held against the Glas, which terminate, or rather environ the Parts that immediately touch the Globe, are luminous, as was said

* 2455. of the Tube *.

EXPERIMENT 5.

2465. We make Use of four Iron Pillars, such as we have mention'd *; Pl.79.F.3. two of them are fastened in the side Holes i, i ; the two others in * 2460.2461. the corresponding Slits. The two Glas Globes G, and H, are applied to the Board, which are turned about by one Rope only, but it is longer than that which was used in the foregoing Experiments. The Globe H has Air in it, G is exhausted; the smallest Distance between the Globes, is equal to a Quarter of an Inch. The Globes being whirl'd about in the Dark, if the Hand be applied to the Globe H, and there is a Friction, the other Globe G becomes lucid, and the Light is of the Figure, represented here. If the Motion of the last Globe be directed towards the contrary Part, the Figure of the Light is turned the other Way; but it remains, whether the Motions of both Globes conspire, or are contrary.

When

When the Friction is left off, but the Motion is continued, it often happens, that the Light continues some Time, before it disappears.

EXPERIMENT 6.

We make use of the same Globe also here, which we used in the third and fourth Experiments; and it is applied to the Machine in the same Manner, that it may be whirl'd about: The upper Part of the Globe is surrounded, at the Distance of about four Inches from the Globe, with a Brass Wire *m p o*, circularly bent in the upper Part, and whose Ends are fastened in the Board. Small Threads are tied to it, which being extended towards the Center of the Globe, come within a Quarter of an Inch of the Surface of the Globe. 2466.
Pl. 79. F. 1.

Whirl the Globe and apply the Hand, and immediately the Threads will be mov'd irregularly by the Agitation of the Air; but when the Glass is heated by the Attrition, all the Threads are directed towards the Center of the Globe, as may be seen in the Figure: And if the Hand be applied a little on one Side, the Threads will be directed obliquely to another Point in the Axis.

EXPERIMENT 7.

If the Air be drawn out of the Globe this Effect ceases.

2467.

EXPERIMENT 8.

Take another Globe different from that, with which the foregoing Experiments were made. In this Experiment the Aperture of the Globe *G* must be larger; that you may put into it a round flat Piece of Wood *o*, that has a Brass Wire *q* joined to it. In order to fix this Piece of Wood in the Middle of the Globe, the Wire is screw'd on to the Cover, which is applied at *b* to the Aperture of the Globe, the Cock *e* is joined to the Middle of the Cover. 2468.
Pl. 79. F. 4.

To the Circumference of the Wooden Circle *o* small Threads are fasten'd, which, being extended, almost touch the inner Surface of the Globe.

Apply the Globe to the Machine before-mention'd *, and turn * it round; and rub it, as was done in the former Experiments: The Globe being heated by the Friction, if you cease to whirl the Globe, and the Hand be taken off, the Threads will immediately stretch themselves out like Radii from the Center towards the Surface of the Globe; yet they hardly remain one Moment at Rest, 2459.

and though the Globe be exactly shut, these Threads are put in Motion by the Agitation of the outward Air, as appears by blowing against the Globe, though you stand two Foot off, or farther, from the Globe. If you bring your Finger towards the Globe, though you do not touch it, the Threads next to it will be attracted by the Finger, and directed towards it; nay, and sometimes they fly from it. If you apply the Hand to the Globe, the Threads will be mov'd violently and irregularly.

EXPERIMENT 9.

2469. And if the Air be drawn out, as in the foregoing Experiment, the Effect ceases, and the Threads (both before and after the Friction) only hang down by their Gravity. If only Part of the Air be taken out, the Erection of the Threads, and their Agitation, take Place.

2470. If we attend to all the foregoing Experiments, the following Conclusions seem to be naturally deduc'd from them, which we do not give out as certain, but very probable; for we must always distinguish Certainty from Probability.

2471. *That Glass contains in it, and has, about it's Surface, a certain*
 * 2457. 2466. *Atmosphere, which is excited by Friction *, and put into a vibratory*
 2468. *Motion; for it attracts and repels light Bodies †. The smallest*

† 2457. Parts of the Glass are agitated by the Attrition, and by Reason of their Elasticity, their Motion is vibratory, which is communicated to the Atmosphere above-mentioned; and therefore that Atmosphere exerts it's Action the further, the greater Agitation the Parts of the Glass receive when a greater Attrition is given to the Glass.

The Action of this Atmosphere produces other Effects also; for to the Friction alone, arising from this Action, we ought to attribute the Light, which appear'd in the exhausted Globe, in the
 * 2465. fifth Experiment *, there being no visible Friction.

2472. *The Fire, contain'd in the Glass, is expell'd by the Action of this Atmosphere, at least it is mov'd with it. For when light Bodies are put in Motion at a Distance from the Glass; the Bodies also become*

* 2455. 2457. *lucid at a Distance *.*

2466. 2464. It is plain, that *this Atmosphere and Fire is more easily mov'd in a*
 2473. *Place void of Air:* For if the Globe be exhausted of it's Air, there can be perceiv'd no Light, nor any Action of Electricity on
 * 2463. 2467. *the Outside of the Globe *, but the Inside of the Globe appears very luminous, and this Fire is perceiv'd to be in greater Quantity in this Experiment, than in that immediately after mention'd *.*

2474. But the Action of the Electricity does also cease on the Inside when

when the Air is drawn out *, which seems to overthrow what we * 2469.
said of the more easy Motion of the Atmosphere in Vacuo : But
yet it is not probable that it shou'd move no whither in this Case.
On the contrary, it seems to go the same Way as the Fire, and to
move that Way where there is the least Resistance ; and that the
ceasing of the Action of Electricity is to be attributed to the want
of Air, by Means of which, *the Threads are mov'd by the Atmo-* 2475.
sphere ; in the same Manner, as Fire, which freely penetrates all
Bodies, *by Means of the Vapour **, or *the Air*, (for there is no * 2442. 2446.
Explosion of Gunpowder without Air) acts upon them violently.

But laying aside Conjectures, though they have a great many Ex-
periments for their Foundation, let us return to other Things relat-
ing to Fire. But several Experiments are to be made in Vacuo, in
which Friction is requir'd, which must be made with the following
Machine.

A M A C H I N E,

Whereby Bodies are whirl'd round swiftly in Vacuo.

G is the Plate of the Air-pump *, upon this is laid the cross 2476.
Piece of Copper ADB, which is fasten'd, by a Screw which goes Pl. 80.
through the Hole v, whereby the Pipe is join'd to the Plate, Pl. 81.
through which the Air is exhausted †. This cross Piece is so dis- Fig. 1.
pos'd, that the Hole l may answer to the Hole in the Middle of * 2143.
the Plate G * ; for which Reason there is below the cross Piece a † 2152.
short Cylinder, standing out, which goes into the Hole of the * 2154.
Plate.

Into this Hole of the Plate, underneath, is put the Collar of 2477.
Leathers p, whose Cover is d *. To this is join'd the Copper Plate * 2155.
nn, to which the small Pillars o, o, made of the same Metal,
adhere.

These being thus join'd together, we put the Axis g a b through 2478.
the Hole l, and through the Collar of Leathers. It's Part a b is
thicker than the rest of it, and has a Screw upon it ; the Part f is
smaller and cylindrical ; the Leathers in the Collar surround this,
and during the turning about of the Axis, these Leathers hinder the
Air from getting in.

To this Axis at g, where it is square, is join'd the little Wheel r, 2479.
which is fasten'd by Means of the Screw b. This Wheel is dode-
cagonal, the Sides being a little hollow'd, that the Angles, whose
Sharpness is taken away, may stand out the more ; the Dodecagon
is inclos'd between two thin round Plates, which are prominent
every

every Way, that the Rope, of which I shall speak afterwards, may be kept in it's Place.

The small Plate *ii*, is applied to the Pillars *o*, *o*, and kept there by the Screws *y*, *y*; this Plate sustains the Axis, whose End *z* goes into the Cavity *k*.

Upon the cross Piece *A D B* stand the two Pillars *C*, *C*, which sustain the Plate *H*, *H*, which is fasten'd with the Screws *m*, *m*. In the Middle of this Plate there is a Piece with a Hole in it, to receive the End *q* of the Axis so often mention'd.

2480. To the Plate *A B* of the cross Piece are applied the small Plates *T*, *T*, upon which stand the elastic Plates *E F*, *E F*. The Plates *T*, *T*, are fastened by Means of the Screws *e*, *e*, *e*, *e*, going through Slits in the Plates into the Holes *x*, *x*, *x*, *x*; and by this Method the Plates may be fastened at different Distances from the Axis.

2481. The Parts hitherto mentioned are of Copper, and are sufficient, when Experiments are to be made, in which there is required a swift whirling about of the Axis, and a greater Friction. The Axis then goes through the Body, which is to be whirled about, and the Bodies, by which it is to be rubbed, are joined to the Plates *E F*, *E F*, as will be explained more distinctly in the particular Experiment.

2482. All this Apparatus is covered by the Receiver *R**, and the Air is exhausted. The Rope is put about the little Wheel *r*, and wooden
* 2157. Handles are joined to the Ends of it, which are held in the Hand.

The Rope being now stretched, if the Hands be moved alternately; the Axis will turn first one Way and then the other.

A D D I T I O N S

To the foregoing Machine, when a more violent Friction, or a Motion for a longer Time, is required.

In these Cases a Wheel must be applied to the Machine.

2483. To the Sides of the Box, which contains the Air-Pump, are applied, and fastened with Screws, Boards three Inches broad, whose Thickness appears at *K* and *K*. To these are joined the smaller Boards *L*, *L*, to which is applied the Board *I I*, in the Middle of which there is a small Brass Pipe, through which the Axis of the Wheel *Q* passes; the other End of this Axis goes into a like Pipe, which is fastened to the solid Wooden Piece, which stands upon the Bottom of the Box, and is fastened with Screws.

2484. The smaller solid Wooden Pieces *N*, *N*, are joined to the Boards *K*, *K*; through these solid Pieces go the Iron Tails of the Wooden
Pulleys

Pulleys t, t ; a Part of which Tails is square, and Part of them makes a Screw. The Rope goes about the Wheels Q and r , and passes over the Pulleys t, t , between which the Rope is horizontal; but one of the Pulleys is raised a little higher than the other. The Rope is stretched, by turning the Screws c, c .

By turning round the Wheel, the Axis is swiftly whirled about, though there is a great Friction between the Body whirled about and the others, which are joined to the Plates EF, EF . The Rope in this last Case must be stretched more.

2485.

EXPERIMENT IO.

Take a Glass Globe of three Inches Diameter, or two Inches and an half, which has a Hole at each Side; the Parts where the Holes are may be cylindrical. The Axis ab * is put through these Holes, that the Globe may be whirled about; the Parts of the Globe, where the Openings are, are covered with the Cork s, s , and it is fastened by Means of the Screws O, O . The lowest of these is fastened, by a smaller Screw a , which goes into the Hole b ; the Globe is fastened by turning the upper Screw.

2486.

Plate 80.

* 2478.

Pl. 81. F. 1.

The solid Pieces of Wood SS , are joined to the Plates EF, EF , and are surrounded with Paper; these solid Pieces are applied closely to the Globe, and fastened by the Screws e, e, e, e .

Every thing else being disposed, as has been said in the Description of the Machine, the Air must be exhausted from the Receiver *.

* 2482.

The Globe, being thus fastened, together with it's Axis in Vacuum, is swiftly whirled about, by the Motion of the Wheel Q , and there is a Friction *.

* 2484.

If the Experiment be made in the Dark, the Globe will appear lucid; and the Motion being continued, that the Globe may be heated by the Friction, the Light is indeed increased, but then it is observed to be fixed in the Places where the Friction is.

2487.

It follows from this Experiment, that *the Fire, contained in Glass, does not want Air, to make it appear*; for the Glass grows hot, and shines, the internal and external Air being taken away.

2488.

The like Experiments may be made with other Bodies.

EXPERIMENT II.

That Quicksilver contains Fire is plain, from Experiments. For if Mercury well cleaned be shaken about in a Glass, it will appear luminous.

2489.

EXPE-

EXPERIMENT 12.

2490. The Light is more sensible in a Place void of Air.

* 2459. If you put a small Quantity of Mercury into a Glass Globe; the Globe may be whirled round, as has been explained before *, which will be delightful to see, if the Glass be moved slowly.

2491. The Globe, that has the Mercury in it, is exhausted by joining to it a Pipe about two Foot long, and by joining the other End of the Pipe underneath, to the Hole in the Middle of the Plate of the Air-Pump *.

* 2154. Then if you cover both that Hole and the Hole through which the Air is drawn out with a Receiver, put upon the Plate mentioned, the Air will be easily drawn out of the Globe.

EXPERIMENT 13.

2492. A small Quantity of Mercury well cleansed is poured into the Glass Bottle A; the Air is drawn out, and the Bottle is exactly closed with a Glass Stopple. If this is shaken about in the Dark, the Mercury will appear luminous.

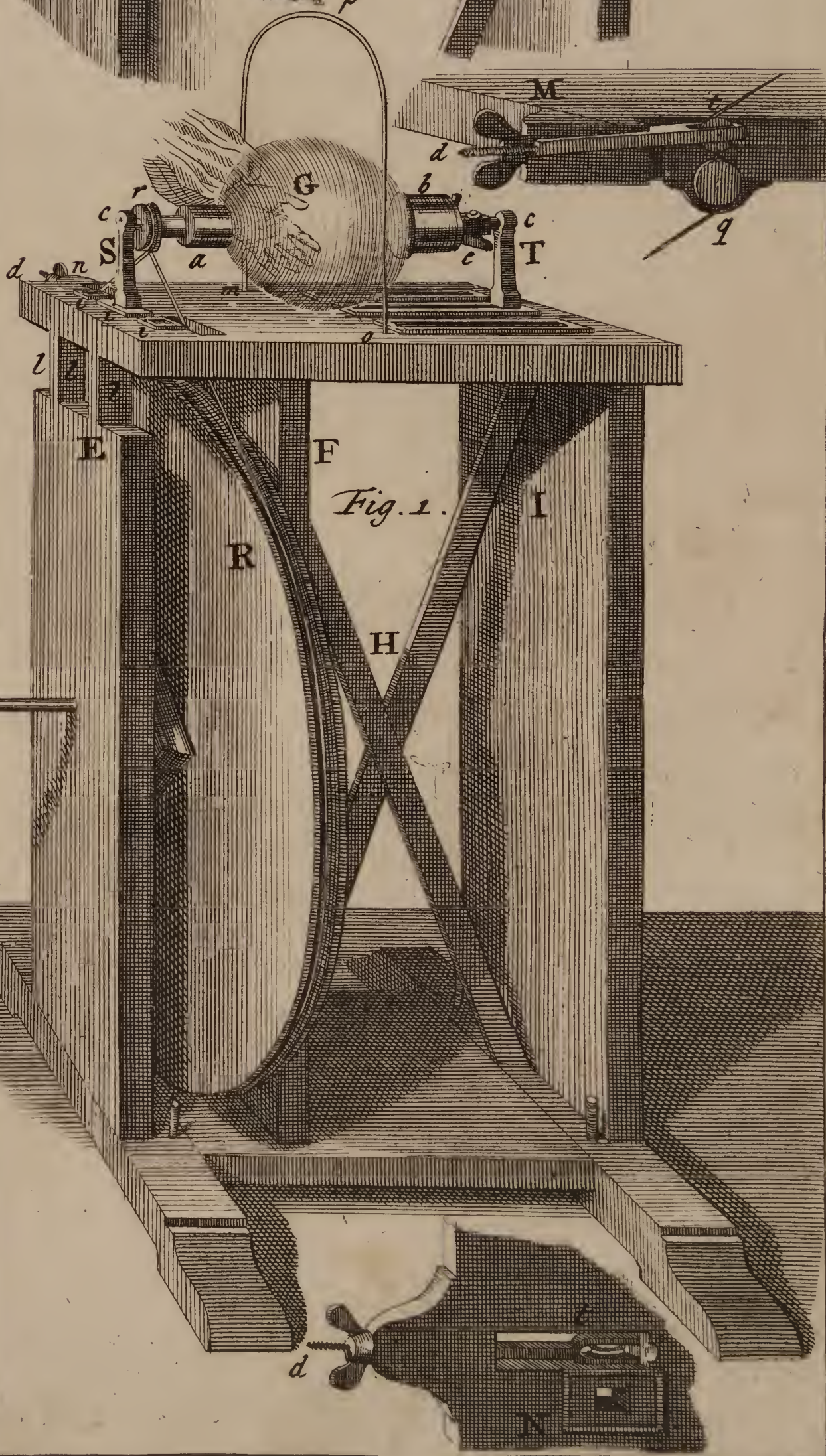
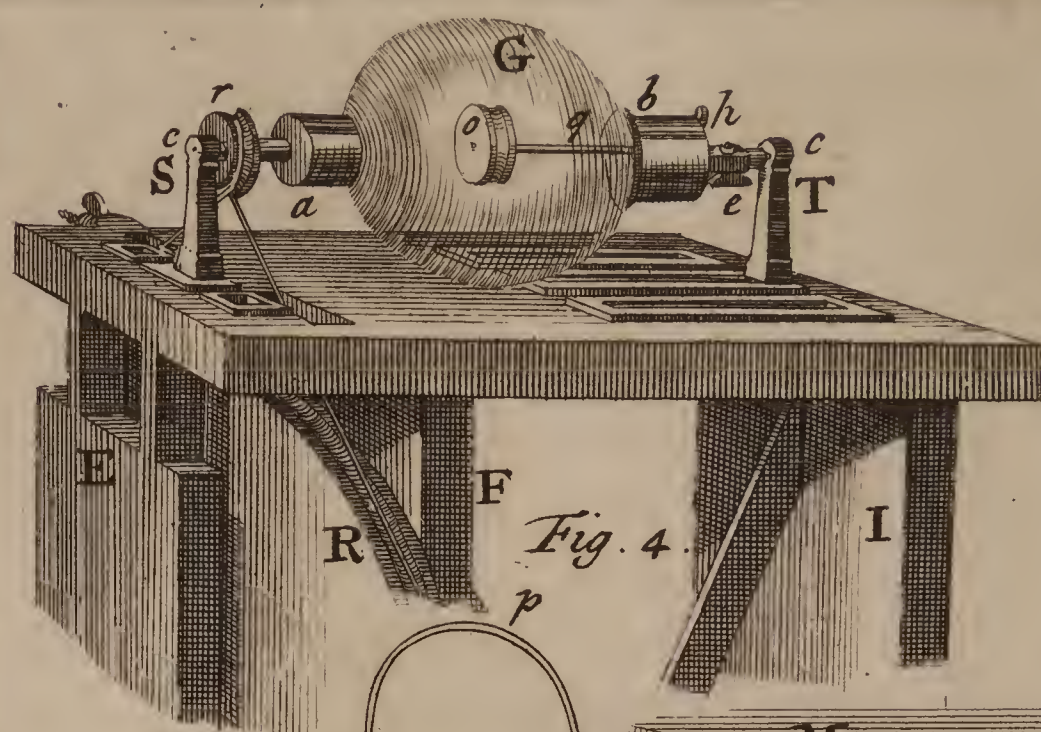
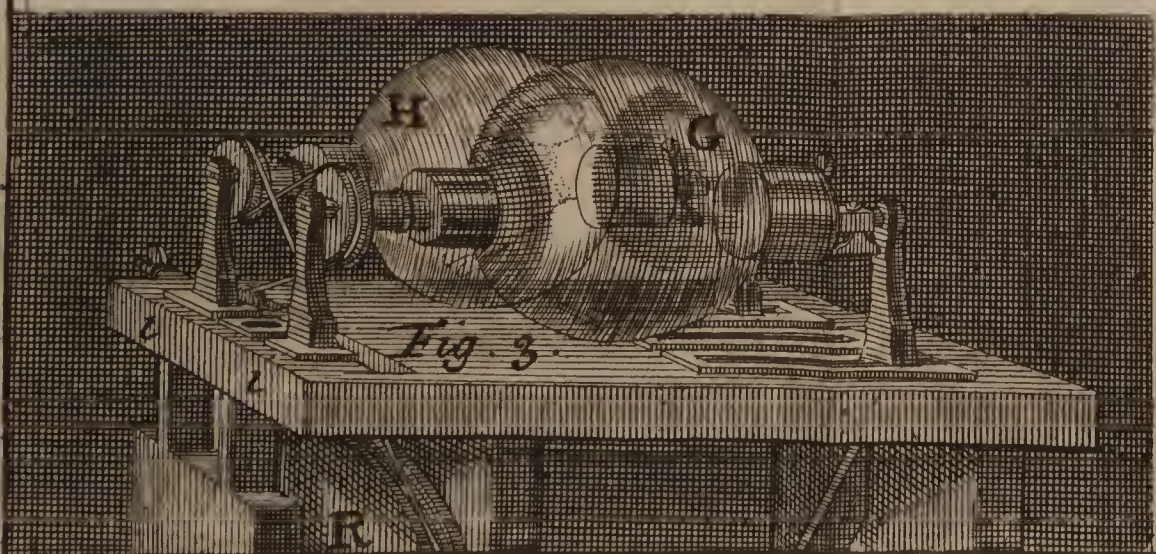
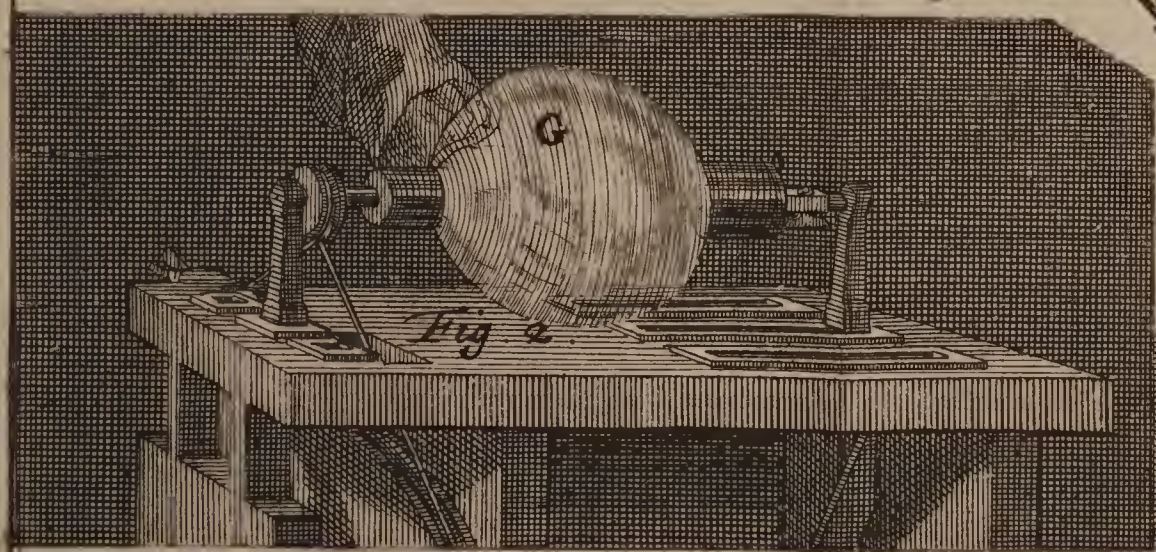
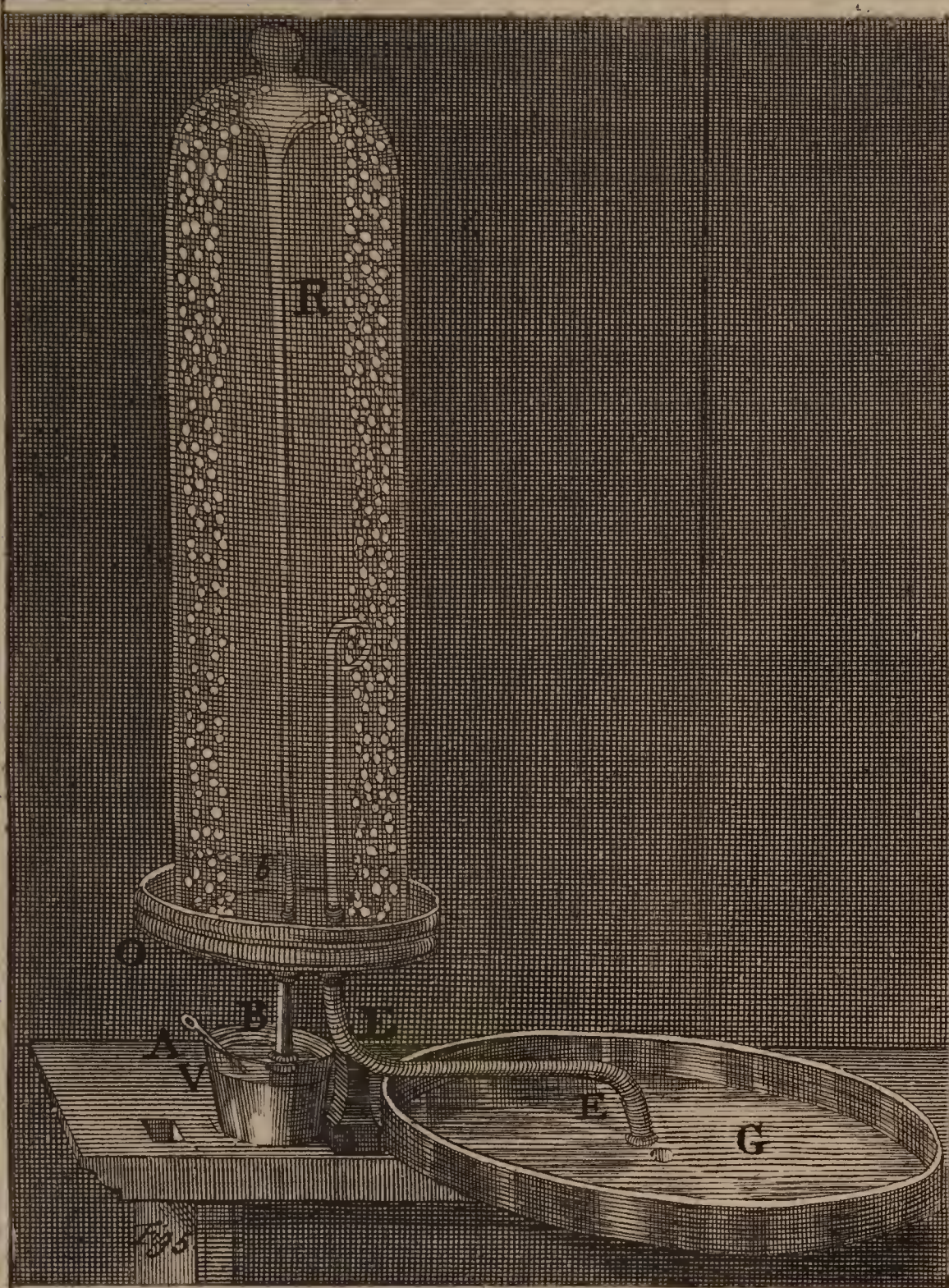
2493. In order to exhaust the Bottle, it is laid upon the Plate of the Air-Pump; it is covered with a Receiver open at Top, and the Aperture is closed with a Cover, to which a Collar of Leathers is joined *. To the Brass Wire, which goes through the Collar of Leathers, is joined a Box, which is filled with soft Wax, into which the upper Part of the Stopple is thrust. The Stopple is sustained by the Cohesion of the Wax, and is so ordered as to answer to the Mouth of the Bottle.

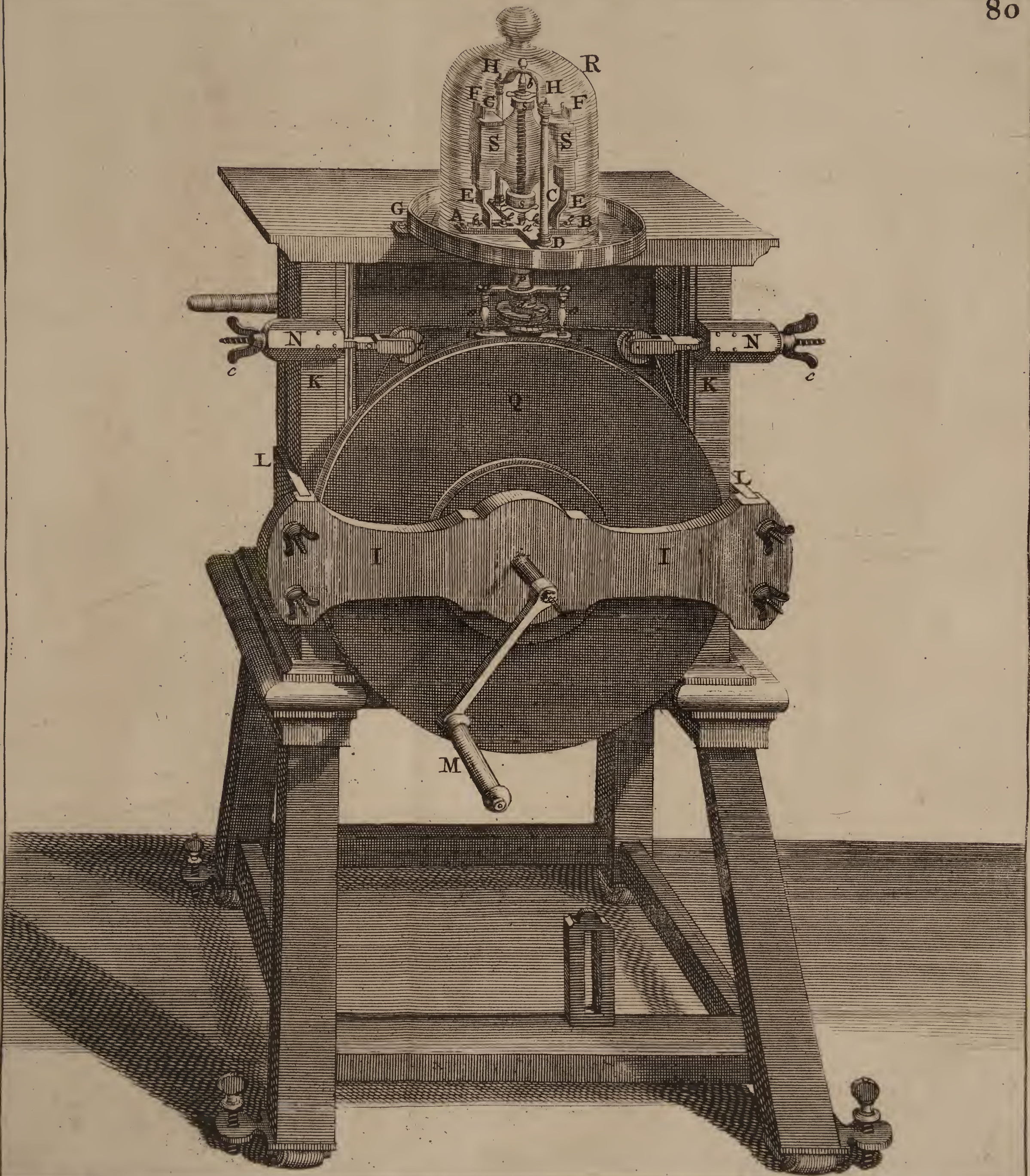
* 2155. The Air is taken out of the Receiver. The Brass Wire is thrust down, and the exhausted Bottle is closed, the Air is admitted into the Receiver, and the Stopple is pressed tight.

EXPERIMENT 14.

2494. Take a Brass Plate O, and screw on to it the Pipe EE, whose other End is screwed to the Air-Pump *, that the Air may be drawn out from the Glass Receiver R laid upon it. The Pipe, through which the Air is drawn out, must stand up beyond the Plate in the Receiver about four or five Inches, be bent, and have a small Hole in it; which must be taken Care of, for Fear any Mercury should get into the Air-Pump.

Pl. 79. F. 5. * 2152. The Middle of this Plate, has a Brass Pipe B, which has a small Glass Tube within it; the lower Part of the Brass Pipe which is shut,





shut, comes down almost to the Bottom of the Vessel V, that contains very clean Mercury: There is an Hole in the Side of the Pipe, exactly shut by the Pin A; there is a Glass Tube at *b*, at the upper End of the Pipe B, standing out, which goes into the Vessel R, and has a small Aperture.

The Height of the Receiver R is about sixteen Inches, and it's Diameter four Inches; pump the Air out of it, and then open the Hole in the Side of the Pipe B, and the Mercury will, by the Pressure of the external Air, violently enter the Pipe, and spout up through the Glass Tube, and strike against the Top of the Receiver R with great Force.

The Experiment must be made in a dark Place, and the Mercury will appear luminous.

Mercury, if Metal is not mixed with it, may be well cleansed by the following Method. We put the Mercury in an open Vessel together with Water and white Sope upon the Fire; when the Water boils up violently, the Mercury is moved about with small Rods; then, by repeating the Lotions with hot Water, the Mercury is cleansed from the Greasiness of the Sope; then it must once or twice pass through a Paper Funnel, whose Spout is small: This dries the Mercury, and clears it of all the Dregs.

2495.

Many hard Bodies emit Light by being rubbed.

2496.

EXPERIMENT 15.

Take two Pieces of Chrystal and rub them together; they immediately become luminous; but the Light is more vivid, where the Contact is.

2497.

EXPERIMENT 16.

If the well known chymical Preparation of Urine, which is called *Phosphorus*, be kept in Water, and then you take out some of it, and roll it up, so as to make a kind of Pencil, with which you write upon a Piece of Paper, the Letters will appear all Fire, if you put the Paper in a dark Place. When you take the Phosphorus itself out of the Water, it will grow hot and smoke; all which shews, that the Phosphorus contains a great Quantity of Fire in it.

2498.

In this Experiment *we may observe that Water acts sensibly upon the Fire contained in the Phosphorus*; for it keeps it in, so long as the Phosphorus is covered with the Water; but as soon as the Water is taken away, the Heat and Smoke immediately shew that the Fire issues out of the Phosphorus.

2499.

C H A P. XII.

Of the weaker Motion of Fire, where we shall speak of the Communication of Heat.

2500. *WE observe a three-fold Motion in Fire.*

2501. The first is that by which Heat is communicated, and Bodies dilated, without any Separation of their Parts, or Change of their Order; this must be treated of in this Chapter.

2502. The second, which differs only from the first in Degree of Intensity, is that by which the Parts of Bodies are dissolved, or move amongst themselves; we shall consider this in the following Chapter.

2503. The third and last is, that it moves in strait Lines, as we discover in Light; of which I shall speak in the next Book.

2504. *One hot Body communicates Heat to another, which is not so hot, upon their mutual Application, but loses some of it's Heat in the Action.*

2505. From whence we gather, that *the Fire moves until* there happens to be an Equilibrium between the Actions of adjacent Bodies: And in that Case we say *the Degrees of Heat are equal.*

2506. It follows from that Equilibrium, that *however different the adjacent Bodies are, these act in the same Manner upon Thermometers.*

EXPERIMENT I.

2507. If a Thermometer be suspended in the Air above the Surface of any Fluid, it will have the same Degree of Heat as a Thermometer, which is immersed in the Fluid, whether it be Water, any Oil, Spirit of Wine, or any other Fluid.

2508. But this Equilibrium in the Actions of the Fire contained in different Bodies will not happen till after some Time.

2509. We further deduce from this Equilibrium, that *in all Bodies the Heat is equally dispersed throughout them.*

2510. As also we see why Bodies separated and surrounded with Air, or any other Fluid, through which the Heat is equally dispersed, do acquire equal Degrees of Heat.

EXPERIMENT 2.

2511. We make use of two Cylinders A and B, the first of Marble, the second of Wood. They are hollowed cylindrically in the Middle in such Manner, that Thermometers may be put into the Hollows of them;

them; we made use of the small ones *c*, *d*, mentioned above *, and * 2449. one of which is represented in Fig. 3.

After the Thermometers are put in, the Apertures of the Cavities are closed; the Stopple *a*, of the Cylinder A, is of Marble, the other *b* is of Wood; by putting Wax round all Communication with the external Air is cut off.

We make use of a third Thermometer also EF, which has also been mention'd above *; this is put between the Cylinders. * 2449.

The Heat of the Air, surrounding the Bodies, being alter'd, the Thermometer EF immediately shews the Alteration; if the Temper of the Air remains the same, the Thermometer *d* will shew the same Degree of Heat; if it be continued, *c* will be disposed in the same Manner. 2512.

I have always observ'd, the Alterations to be thus successive, and lastly equal, for many Months.

It is moreover manifest from hence, why the Steam of the Surface of boiling Water, included in a Vessel, has the same Degree of Heat as the Water; and why the Heat is not increased when the Vapours are accumulated; and not diminish'd, when even a great Quantity of Fire goes out of a given Hole along with the hot Vapours. 2513.

We have said that Bodies of the same Heat act in the same Manner upon the Thermometer, and this happens, because of the small Quantity of Liquor contain'd in the Thermometer; these Actions do not sensibly change the Heat of the Bodies. 2514.

But in many other Cases Bodies equally hot do not act after the same Manner upon the same Body; neither in different Bodies, encompassed by the same Fluid, equally hot every where, will the Heat become equal to the Heat of the Fluid itself in the same Time; as we have seen in the last Experiment. 2515.

Whence it follows that *some Bodies are more difficult to be heated than others*, and that from a twofold Cause: For the Parts of all Bodies are not mov'd with the same Ease, and Fire enters some with more Difficulty than it does others. 2516.

It is manifest, that in Heat there is requir'd a certain Agitation of the Parts of a Body; because upon increasing the Heat, this Agitation becomes sensible: But the Parts of Bodies are different, and these in different Bodies do not only differ in Density but Cohesion too; and therefore the Agitation cannot be communicated to them with the same Ease; consequently unequal Actions of Fire are requir'd to the Communication of equal Degrees of Heat: And *the Heat is not proportional to the Quantity of Fire.* 2517.

2518.

EXPERIMENT 3.

2519. If a Person puts both his Hands, when they are equally hot, one upon Wood, and the other upon Marble, both equal in Bulk, and equally hot, but the Heat of which is sensibly less than that of the Hands; the Hand, which lies upon the Marble, will lose more Heat, and communicate a less Degree of Heat to the Marble, than that Degree which the Wood has acquir'd from the Hand laid upon it, which does not lose so much Heat. These Things are so sensible, as to require no other Measure.

2520. It is also manifest from Experiments that *Fire does not penetrate all Bodies with the same Ease*. This is what we have observ'd already

* 2400. ready*, as likewise that *the hotter the Body is, the more easily will*

2521. *Fire penetrate into it*. A burning Speculum produces a less Effect,

2522. that is, reflects a less Quantity of Fire when it's Heat is increased; which is a Sign that there is a great Quantity of the adventitious Fire that enters into the Speculum and there stays.

2523. Also the Effect of this Speculum is diminish'd, when the Sun's Rays pass through the Air which has been already heated by them; and this shews that Fire enters hot Air in a greater Quantity than it does cold Air.

2524. *Those Bodies which are the most difficult to heat, preserve their Heat the longest*, whilst they communicate Heat to less hot, adjacent Bodies.

2525. When a Body gives Heat to such Bodies as are near it, the Parts in it's Surface lose some of their Heat, to which Parts the Fire contain'd within the Bodies does then come; therefore the Diminution of the Heat is successive, and the central Parts keep their Heat the longest.

2526. Hence we see, that *a Body may keep it's Heat a long Time, if it be involv'd within other Bodies*; and the Heat will continue a longer or shorter Time, according to the Difference of the Bodies in which it is involved.

2527. This appears by daily Experience, and particularly is observ'd in *hot Water*, in which *the Heat is preserv'd by the circumambient Air*.

EXPERIMENT 4.

2528. Take two equal Vessels, about three Inches high, and about an Inch and half wide, or less. Put an equal Quantity of boiling Water into each of them; let one of them be set upon the Air-Pump Plate, and exhaust the Air out of the small Receiver put over it.

it. Whilst the Pressure of the Air is diminishing, the Water boils violently, and Fire goes out of it. For the Air being let in, we find the water to be warm; whilst the other, which remain'd expos'd to the Air in the open Vessel, loses only a little of it's Heat.

One may observe something like this in Wood that emits Light; for some Wood that is rotted in the Ground emits Light, when it is taken out; the Earth that encompass'd the Wood kept in the Fire, which goes out when that is remov'd, and the Wood continues to emit Light for some Days. In an exhausted Receiver, the Light is soon destroy'd, and is not restor'd by the Re-admission of the Air.

2529.

Whilst Fire expands itself every Way, and increases the Heat of adjacent Bodies, it does not tend to all Parts with the same Ease*; but if it's Motion towards some Parts be more difficult, it will be increased towards other Parts; as may be observ'd in a Plate, or Iron Cylinder, having one End red hot, and the other no sensible Heat; for if the red hot End be immers'd in cold Water, the other End will grow hot.

2530.

2520.

The Fire which enters into Bodies, puts their Parts into Motion*; the Parts mov'd act upon the Fire contain'd in them, and increase the Motion of it; therefore, when extraneous Fire acts upon a Body, *the Heat thereof is not only increas'd by the Action of that Fire, but also by the Increase of the Fire that was within the Body before*; great Fires confirm the Truth of this, and demonstrate that it is so in all burning Bodies; for we can form a Judgment of what happens in small Motions, from what is sensible in great ones.

2531.

2517.

2532.

We shall now speak more particularly of that increas'd Motion.

C H A P. XIII.

Of the more violent Motion of Fire. Where we shall speak of the Dissolution of Bodies, caused by the Action of Fire.

WHEN the Motion of Fire is increas'd, the Effect of it is the turning of a Solid into a Fluid*, and of this last into an elastic Fluid, as has been seen*. But when the Heat of the Fluid is increas'd, before it is turn'd into an elastic Fluid, the Parts of the Body itself have a most violent Agitation amongst one another, so as to cause the Fluid to boil: For performing which Effect,

2533.

2437.

2440.

2534.

the Action of the Fire need be so much the less as the Fluid is less compress'd.

EXPERIMENT I.

2535. Pour warm Water into a Glass Vessel, and put it on the Air-Pump Plate; cover it with a Receiver, exhaust the Air, and it will boil violently. It is manifest enough how the increase of the Compression causes it to boil with more Difficulty.
2536. And the greatest Degree of Heat that the Fluid can acquire, depends upon that Compression, as may be gather'd from the Experiment above-mention'd *.
- * 2528. 2537. The small Parts of all Bodies are not such, that the Bodies become Fluids upon the lessening of the Cohesion of those Parts, notwithstanding their being separated from one another by the Action of the Fire.
2538. The Solution of Bodies when they become Fluids is call'd Fusion: And the Conversion into an elastic Fluid is call'd Evaporation, and Exhalation. Also the third Separation of Parts above-mention'd *, is call'd the Combustion or burning of Bodies, and sometimes their Calcination.
2539. We have already spoken of Fusion, Evaporation, and Exhalation *; what has been said, may also be referred to Combustion and Calcination: But their Difference must be attributed to the Frame of the Bodies themselves.
- * 2437. 2440. 2540. But what relates to Combustion and Calcination, is deduced from what has been said about Heat *; who does not perceive, that upon the Increase of the Motion of the Parts, they must at length be dissolv'd.
- * 2436. 2517. 2541. But before we speak of Combustion, *the Parts* themselves, *separated in Exhalations*, must be consider'd.
- These *being intimately join'd with Fire fly off by the Motion of the Fire*. Amongst these the Particles of Water turn'd into Vapour are remarkable; which demonstrate, that Fire and Water are not such opposites, as is commonly thought; for the *Fire adheres to all the watery Particles*, and hinders them from joining with the neighbouring Particles; but the Fire *can no way alter them*; for upon the absence of that, they meet again, and are restor'd to Water.
2542. 2543. Vapours ascend on high through the Air, and are sustain'd at different Heights, according to the different Constitution of the Vapours themselves and the Air *. They are often not perceiv'd; then
- * 1477. 2110.

then if their Heat be diminish'd, they come nearer one another and form Clouds ; if there is a greater Diffipation of Fire the Vapours return again to Water, and fall in Rain.

We also observe that Vapours in the Air, which were invifible, appear on a fudden, if the Denfity of the Air be diminish'd 2544.

EXPERIMENT 2.

This Experiment may be made with the Air-pump, when any Experiment has been made with Water in Vacuo. When the Air is let in the Vapours for the moft Part adhere to the inner Surface of the Receiver ; but if the Glafs be clean, they immediately recede, if the Pump be work'd anew, to extract the Air again ; then nothing appears in the Receiver ; but if you continue to exhaust the Air the Vapours become vifible ; which are taken out with the Air, if this be all exhausted. 2545.

There are many Exhalations different from thofe of Water ; all thefe, as they are feparated from Bodies by the Action of Fire, contain a great Quantity of Fire ; and fome particularly confift of Particles, which may be burnt, of which I fhall fpeak prefently. What elfe belongs to this Matter, and is not foreign from our Design, has been explained in the third Chapter of this Book. 2546.

The feparated Parts of moft Bodies, that are burned, are earthy, watery, and oily or fpirituous. 2547.

We call earthy Parts thofe that remain after the Body is diffolv'd by the Fire, that is, the Afhes, which indeed may be hot, but cannot be burned. 2548.

We call thofe watery Parts, which are chang'd into Vapours, and expell'd by the Action of the Fire ; but which, being collected together, upon the leffening of the Heat, are turned into Water. 2549.

Laftly we call thofe Parts oily and fpirituous, which are the only Food of the Fire, by whose Action they are diffolv'd, whilst thofe Parts increafe that Action. 2550.

Thofe Parts are fo diffolv'd by the very violent Action of the Fire, that there is no forming a combuftible Body of them anew : Then thefe are faid to be confum'd : But if the Action of the Fire upon thefe Bodies be lefs violent, they will indeed be turn'd into a thick elastic Fluid, which we call Smoke ; but this is combuftible, and when collected together, forms a foft Body, which is alfo capable of burning. 2551.

When the Heat of thefe Parts is increas'd fo much that they burn, they will emit Light, and form Flame during their Separation from. 2552.

from the Body ; so that Smoke and Flame have no Difference but in their Degree of Heat ; and Smoke upon increasing it's Heat will be turned into Flame, and by that Means be consum'd.

EXPERIMENT 3.

2554. Having blown out the Candle C, which sends out the Smoke
Pl.81.F.5. F, let another lighted Candle A be brought near it ; the Smoke of the first will be chang'd into Flame, and by that Means the Candle C will be lighted, which is fix or eight Inches distant from the other.

2555. We must observe, with regard to *Flame*, that it *has the Figure of a Pyramid* in the Air : The Reason is this ; the Flame is lighter than the Air, and so ascends ; but the Parts which form it, are constantly dispers'd, with a very violent Motion, and therefore it is continually less'n'd, and but a few Parts come to the upper End of the Flame, which therefore is very slender.

2556. Setting aside this Diffipation, Flame is cylindrical ; for it continually tends towards a spherical Figure ; but it is carried upwards, and the ascending Parts are supply'd by new adventitious Parts. For this Reason Flame may be very much extended ; if, whilst it is surrounded, this Diffipation is prevented, or at least diminish'd.

EXPERIMENT 4.

2557. Join together four Candles at C, to make the Flame the thicker ;
Pl.82.F.1. and let it pass through the Tube AB, which is broadest at A, and almost a Foot long. The Flame will ascend above the Tube to D in such Manner, that the Height BD will want but little of the whole Length of the Flame, when the Tube is laid aside.

2558. If, upon lessening the lateral Diffipation, the Flame be left to itself, which happens, *when a denser Flame is encompass'd by a more subtile Flame, the former will extend itself very much, and also be dilated laterally.*

EXPERIMENT 5.

2559. Pour Spirit of Wine into the Brass Cylinder C, which is three
Pl.82.F.2. Inches wide, and two high, to the Height of about three Quarters of an Inch. Put the Cylinder on the Fire, and set the Spirit of Wine on Fire. Put a Piece of a Wax Candle into the small Pipe a, an Inch high, which has a bent Tail join'd to it, which Candle must not stand out above the Pipe. Light the Candle, and put it into the Flame of the Spirit of Wine, which then surrounds the denser

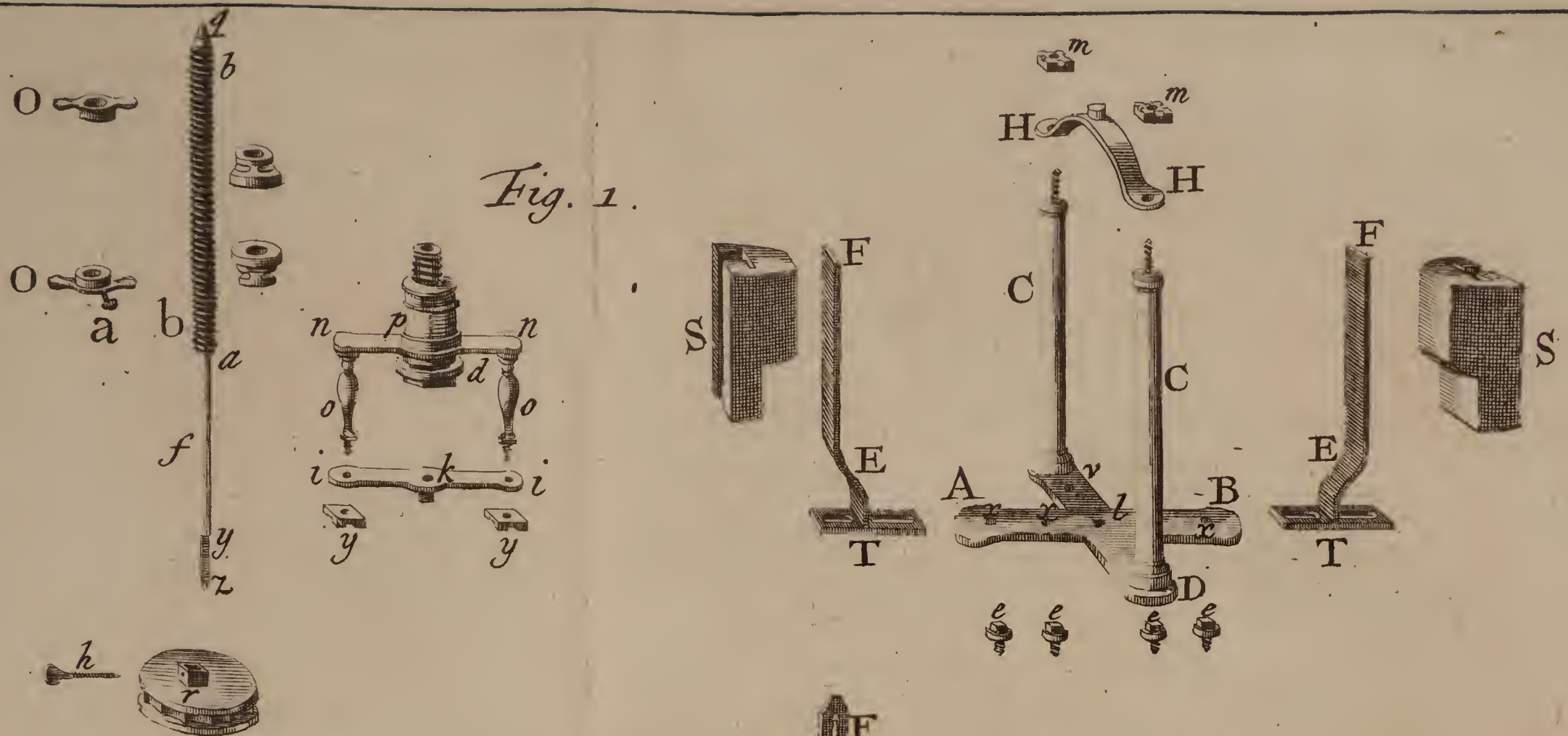


Fig. 3.

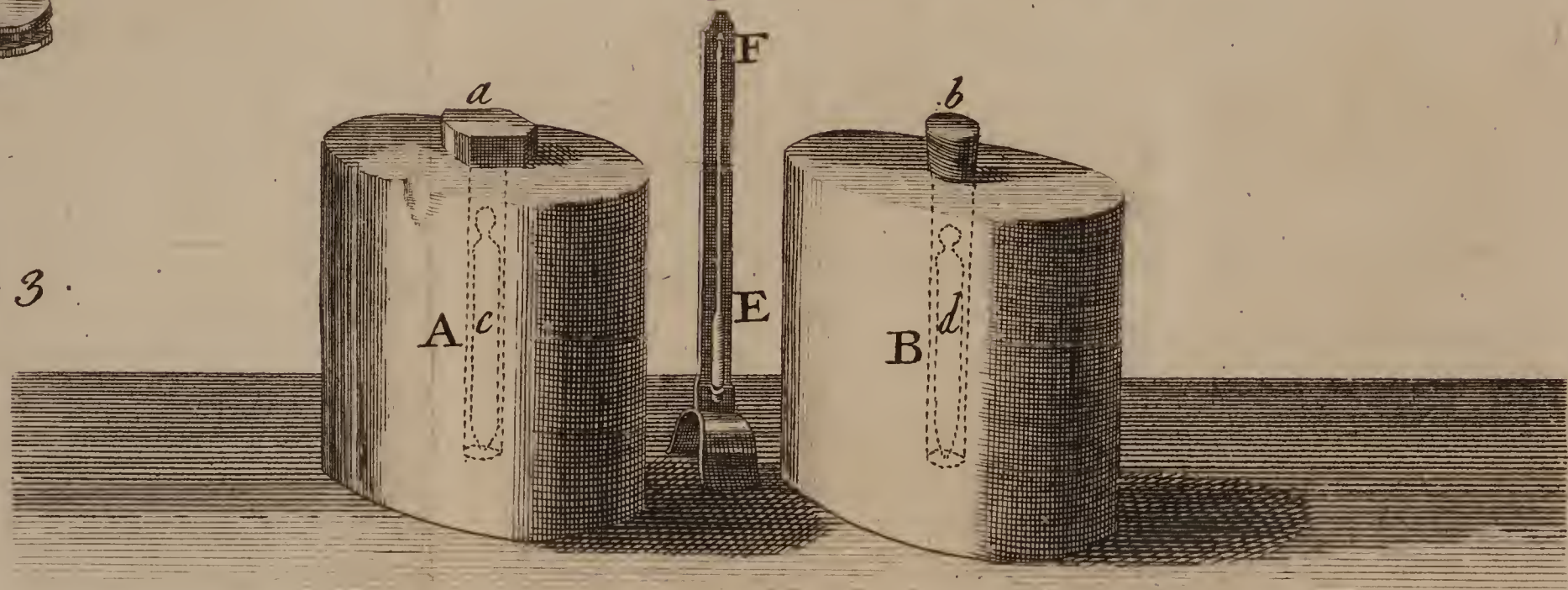


Fig. 4.

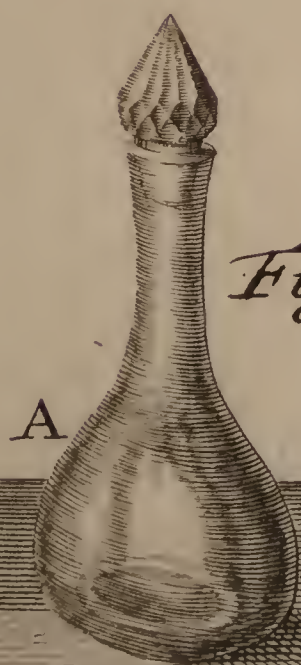


Fig. 2.

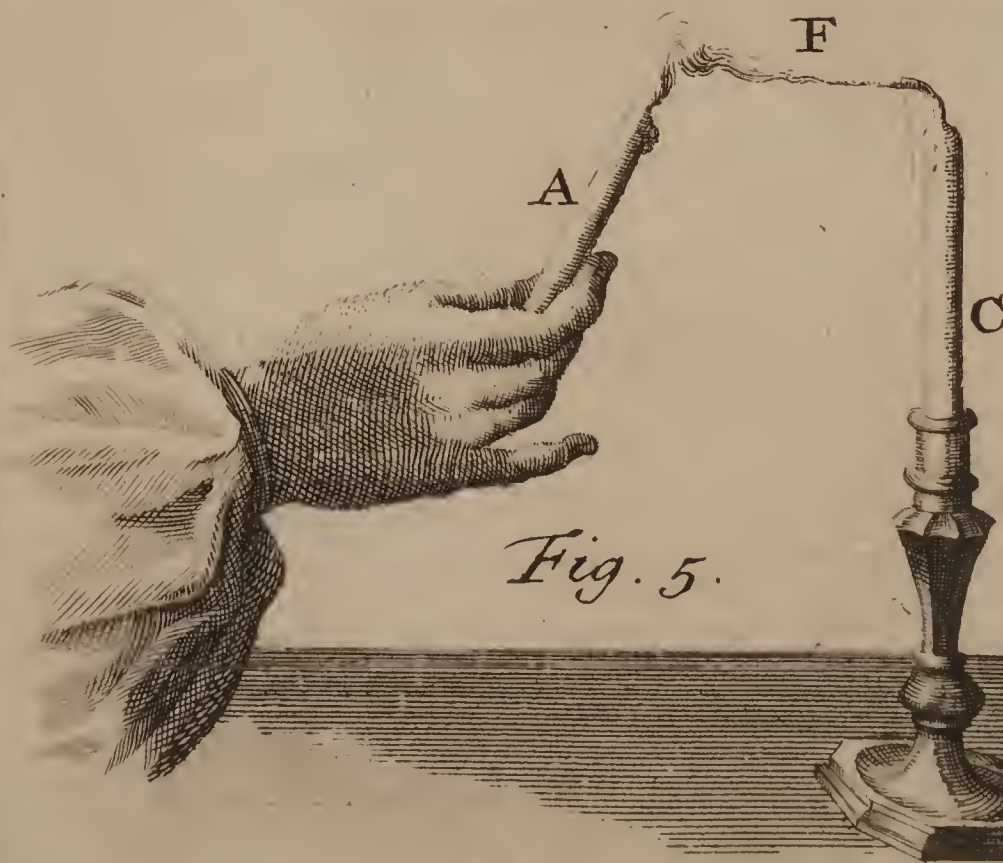


Fig. 5.

denser Flame of the Wax ; this is dilated, and ascends higher, than it wou'd if left to itself.

The Exhalations, which may be burnt, and are therefore inflammable, mostly, if not entirely, consist of the Food of Fire ; which, by Reason of the Fire's acting already upon the Particles *, * is very easily to be set on Fire. 2560. 2541.

We see this in Mines, in which oftentimes, when Flame is brought near them, the Exhalations immediately take Fire with an Explosion. There is always this Explosion, when Flame is generated on a sudden. 2561.

Exhalations often take Fire of themselves ; which is sometimes to be attributed to the Sun's Rays, collected in passing through the Clouds, or by Reflection from them. For the Rays of the Sun, when collected by convex Glasses, or Specula, produce incredible Effects, as will appear in the following Book, and the Clouds can do something like this. Exhalations may also be set on Fire by the Mixture of various Exhalations, in which, by the mutual Action of the Particles, Fire may be very violently excited. Experiments lead us to this Conclusion ; for we discover in many Cases, a mutual Action of Particles, in the mixing of Bodies, whereby Fire is excited. 2562.

The Chymists furnish us with many Instances ; whereby it appears, that two Bodies which are often very cold, by only being mixt together, will take Fire ; though they are both Fluids. 2563.

Who will deny that there is something like this in Exhalations, if he considers that the Particles of which Exhalations consist exist separate from the Bodies, because they are mov'd by the Action of the Fire, which coheres with them *. * 2564. 2541.

We make sensible by the *Boylean* Experiment, the mutual Action of mixt Exhalations, although less violent.

EXPERIMENT 6.

We make use of two Phials, one of which contains Spirit of Salt, and the other Spirit of Sal Ammoniac well rectified. When these are open'd, Exhalations rise out of them, but they are invisible, as long as the Phials are at some Distance from one another ; but if they be dispos'd in such Manner, that the Exhalations may be mixt together, they immediately become visible, and ascend, having the Appearance of Smoke. 2565.

The Exhalations which take Fire in the Air are the Causes of several Phenomena ; to these we must attribute fiery Meteors, as Lightnings and others. 2566.

We must now return to what relates to the Action of Fire upon Bodies.

2567. In Bodies, that are calcin'd, there are either none, or but a small Quantity of those Parts, which are the Food of Fire, wherefore before these Bodies can be dissolv'd, it is necessary that the extraneous Fire should continually act upon them.

2568. But many things seem to shew that the Fire cannot immediately exert such an Action upon Bodies, as we observe in Combustion and Calcination.

2569. In Combustion, the Fire unites itself with innumerable small Particles, which can no Way be perceiv'd; these are mov'd every Way, the greatest Quantity arising from those Places where the Flame is. It can scarce be doubted that these Particles, as they move

2570. along with the Fire, enter into the Pores of other Bodies; for *it is manifest from many Experiments*, most of which are mention'd by Boyle, *that the Weight of Bodies is sensibly increas'd by the Action of Fire*; and particularly if the Flame acts immediately upon them; although the Weight of Bodies, inclos'd in a Glass, if the Glass is expos'd to the Flame of Spirit of Wine two or three Hours, will also be sometimes increas'd, but in a less Degree. This Increase of

* 156. Weight, proves the Accession of new Matter *, which has penetrated the Glass. But that this Increase of Weight cannot be attributed to the Fire, other Experiments prove, from which it ap-

2571. pears, that *the Weight of Fire, if it has any, is not sensible to us*; which if it appears from one Experiment only, it is manifest that, in all Cases, in which an Increase of Weight is discover'd, this is to be attributed to some other Matter, carried with the Fire.

EXPERIMENT 7.

2572. Lay a Piece of red hot Iron upon the Scale of a very accurate Balance, and make an Equilibrium. If you leave it thus, the Equilibrium is preserv'd, whilst the Iron loses this greater Heat, and is reduc'd to the smallest Degree of Heat.

2572. Iron is dilated by Heat *; and is sustain'd more by the Air †; therefore it may be imagin'd that there must be an Increase of the Weight, to make an Equilibrium. But the Difference from this Cause cannot be sensible in the Experiment, and we speak of a greater Increase of Weight *.

* 2570. The last Experiment proceeds in the same Manner in Vacuo.

EXPERIMENT 8.

We make use of two Iron Cubes, having their Sides equal to an Inch, and which are exactly of the same Weight; one of them is to be put into the Fire, being first laid in a Vessel, or Crucible, that nothing may adhere to it. 2574.

A small accurate Balance is suspended over the Plate of the Air-Pump, in the Method explain'd above *. The Scales must be suspended by Chains, and both the Chains and the Scales must be thicker, than what are commonly used in such small Balances. * 2167.

When the Iron is red hot, it is laid upon one Scale, and an Equilibrium is made with the other Cube; if any thing is wanting, it must be made up with a small Weight. All this must be cover'd with a Glass Receiver, and the Air exhausted, and the Equilibrium remains; which is not in the least alter'd, by the Diminution of the Heat of the Iron.

It is confirm'd by Experiments, even some that have been made in Vacuo, that the Action of Fire in burning of Bodies, is assisted by the Action of a very subtile extraneous Body, which is united with the Fire. For all Combustion ceases, upon the Removal of the Air, as will be seen in the next Chapter. 2575.

Yet Bodies which are to be burnt in the Air, can be consum'd by Fire, when the Air is remov'd, but only by a continual Action of extraneous Fire, and indeed more slowly, the Flame, and violent Agitation of the Parts, ceasing. 2576.

EXPERIMENT 9.

The small Pieces of Wood *a, a, a, a*, are join'd together by a Wire, which is fasten'd to the End *S*, of the Brass Wire *ST*, Pl. 82.F. 3. which passes through the Collar of Leathers *P* *, which is screw'd * 2155. on to the Cover *O*, which is laid on the Receiver *R*. 2577.

The red hot Iron *F*, is laid upon the Plate *G* of the Air-Pump, the Stone *L* being put between; it is cover'd with the Receiver *R*, and the Air is exhausted. If you push down the Brass Wire, the small Pieces of Wood are laid on the Iron successively, and there consum'd; but they emit no Flame.

When a Flint is struck with a Steel, Particles are separated from the Steel and the Stone; they are fiery, and make Sparks, in their Separation: The melted Particles of Metal acquire a spherical Figure; those which are separated from the Stone, are consum'd, are friable, and are reduc'd to a Calx. If the Percussion be made 2578.

in Vacuo, we discover the same Changes ; but the Parts, whilst they are separated, do not become lucid, and there are no Sparks to be perceiv'd.

EXPERIMENT 10.

2579. We make use of the Machine, describ'd above, for Friction in
 * 2476. Vacuo * ; with it's Adjuncts, that the Circumrotation may be with
 * 2483. the greater Wheel *.

But before we join the Machine to the Plate of the Air-Pump, we lay a Leather on the Plate, upon which Leather the Glafs Receiver must be put * ; we also apply to the Plate a Piece of Paper, which must be contain'd in the Receiver in such manner, that it may not hinder the Receiver from being applied to the Leather, Part of which only is cover'd with the Paper ; this has two Holes in it, which answer to the Holes in the Air-Pump.

Pl.82.F.4. To the movable Axis *ab* we join the steel Cylinder A, of a small Height, through the Center of which the Axis passes, and whose Diameter is about two Inches and an half, and Height half an Inch.

The Convex Surface of this Cylinder has Grooves, in such manner that the Eminences between the Grooves make Edges, which encompass the Cylinder ; these Edges have eight or ten Incisions, at Right Angles to them.

The Cylinder is fasten'd between two small round Pieces of hard Wood, by the two Screws *c, c*, which are screw'd on with Keys, that the Cylinder may be well fix'd.

- Two Pieces of Flint must be put into the Pieces of Wood *S, S*, which are applied to the Plates *EF, EF*. The Flints must be mov'd to the Circumference of the Cylinder, and press'd close to it, in such manner that the Plates *EF, EF*, may be bent downwards a little, and in this Position they are fasten'd by the Screws
 * 2480. *e, e, e, e, **.

All this must be cover'd with the Glafs Receiver, and the Wheel must be turn'd round ; the Particles which are rubb'd off fall upon the Paper, and must be gather'd together ; and these being all remov'd, the Receiver must be laid on again, and the Air exhausted.

Turn the Wheel again, and having let in the Air, remove the Receiver, and gather together again the Particles, which have been separated from the Steel and Flints.

2580. If these collected last, be compar'd with the first, which were collected before the Air was exhausted, these will be found to be like

like the others, if we examine them with a Microscope. If the Experiment be made in the Dark, we observe, during the turning about of the Wheel, that the Receiver is in a manner fill'd with Sparks, when there is Air in it; but when there is no Air we perceive no such Thing, and the Light appears fix'd where the Friction is; the Stones being made lucid by the Friction, as we have seen in other Bodies *.

* 2486.

C H A P. XIV.

Of the Extinction of Fire, and of Cold.

*THE Extinction of Fire is a Cessation of it's Motion in that Body wherein the Food of the Fire is wasted *.*

2581.
* 2550.

It is very evident that Fire must necessarily be extinguish'd, when all its Food is destroy'd by the Action of the Fire. But it is very difficult to account for the Extinction of Fire, when it has some Food yet remaining.

This we often observe when burning Coals are expos'd to the Sun's Rays; for they are put out before they are quite consum'd, as may easily be try'd. But it is very hard to shew how it comes to pass.

2582.

Fire also goes out where there is no Air.

2583.

EXPERIMENT I.

Take a red hot Coal of hard Turf, which wou'd not go out of itself, without being quite consum'd, and put it into an open Vessel, laying it on the Plate of the Air-Pump; cover it with a Receiver, exhaust the Air, and the Coal will be extinguish'd in a short Time. If, immediately after the taking out of the Air, the Air be let in again, in that short Interval of Time, the Coal is not entirely consum'd, but is reduc'd to that State, that, That which burnt violently, may now be very safely handled.

2584.

The Cause of this Phenomenon cannot be so easily discover'd; for Experiments demonstrate that *this Effect cannot be attributed to the Diminution of the Pressure alone.*

2585.

EXPERIMENT 2.

A Glass Receiver, open at Top, is laid upon the Air-Pump; this is clos'd with a Cover, to which is join'd a long, curve, Brass Tube, which has an Iron End, a Cock being put between.

2586.

The

The Air is exhausted from the Receiver, and let in through the Tube, which is join'd to the Cover, and so dispos'd, that the Air cannot enter into it, without passing through the Flame of red hot Coals. The Air is let in slowly, and when the Receiver is fill'd with it the Cover is taken away; and the Air in it sustains the Weight of the whole Atmosphere. Now if we put into the Receiver through the upper Hole burning Sulphur, or Paper set on Fire, it is immediately extinguish'd upon it's Entrance into the Receiver.

2587. If this be repeated several times, the Flame may be thrust in more and more continually, before it will be put out; because it drives out the Air from the Places that it comes to, and new Air immediately succeeds.

2588. Whence it follows, that *some peculiar Particles are requir'd, that Fire may not be extinguish'd*, which fly off by the Action of the Fire, or become useless, which happen'd in the last Experiment, before the Entrance of the Air into the Tube.

This is illustrated by another Experiment also.

EXPERIMENT 3.

2589. A lighted Candle is cover'd with a Receiver, open at top; and that the Air may not come in at Bottom, we lay the Candle, together with the Receiver, upon the Plate of the Air-Pump; and we make use of a Receiver, which may be applied very close to it, as in the Experiments concerning Air. The Flame remains in the same State, new Air coming in continually at top; but if a Cylinder be join'd to the upper Aperture, that the Air cannot so conveniently get in, the Candle will be put out in a short Time; unless the Receiver be rais'd up a little at one Part, that the Air may come in at the Bottom; or be admitted, any other Way.

2590. The several Ways by which Fire is extinguish'd, must be refer'd
2591. to the want of Air: Thus *Fire which is every Way inclos'd, is extinguish'd in a short Time*; to the Performance of which it seems, that the accumulated Smoke does not a little conduce.

2592. That Extinction is oftentimes such, that the Fire extinguish'd will not be re-kindled, but by bringing new Fire to it, though sometimes, upon the Admission of the Air, it will re-kindle of it's own Accord, and that too when all Communication with the external Air has been a considerable Time taken away. Yet in some of these Cases the Fire is not quite extinguish'd, although there is not a sensible Appearance of the Consumption of the Fire's Food.

Fig. 3.

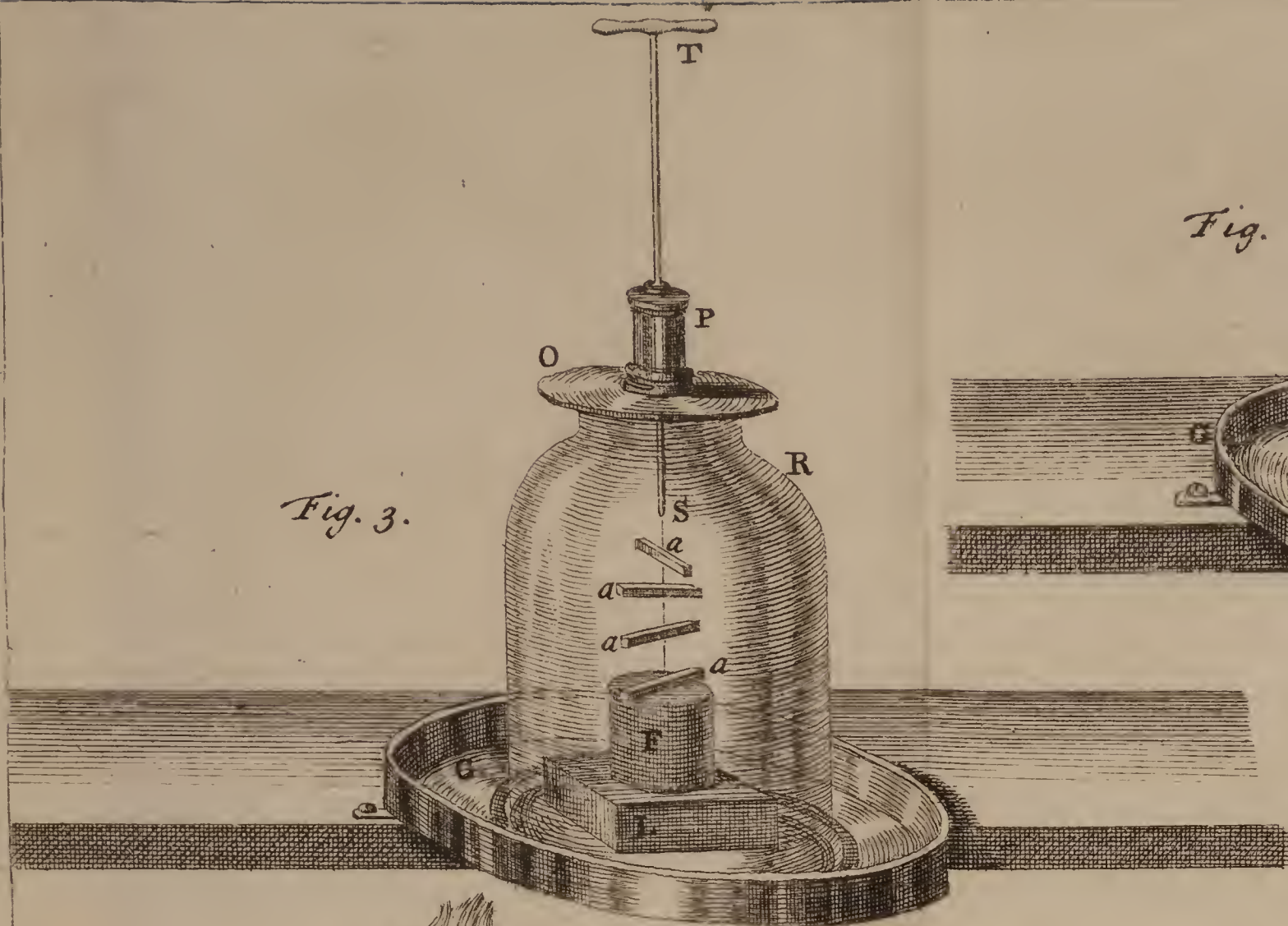


Fig. 4.

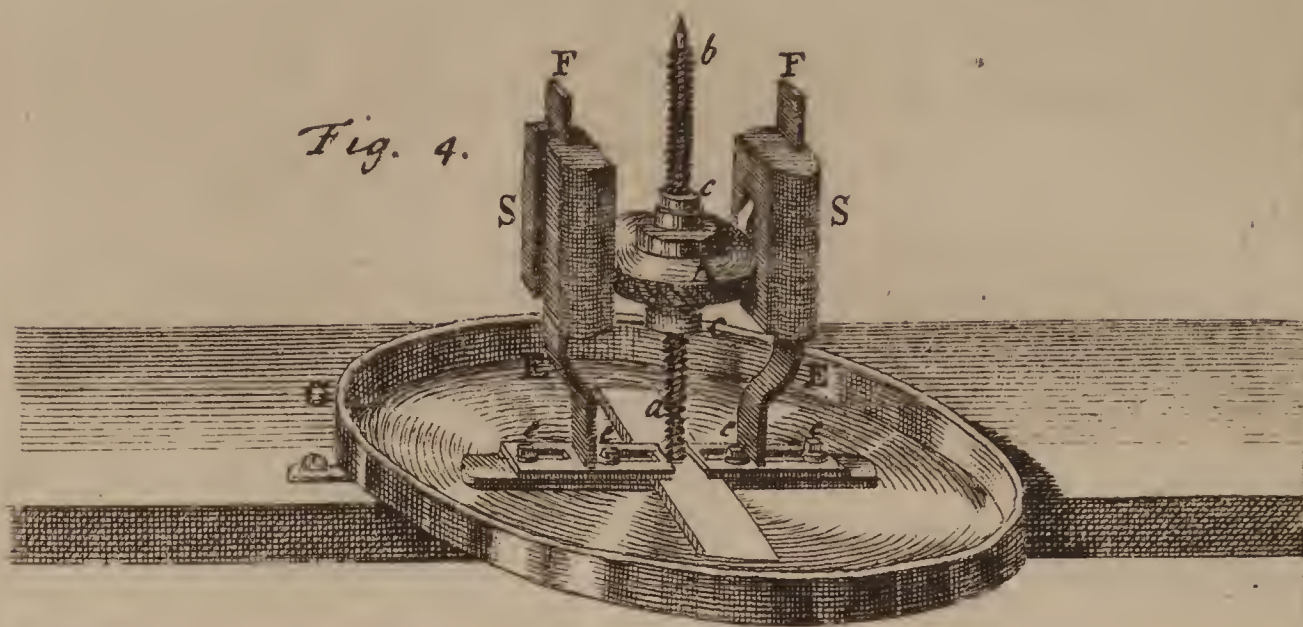
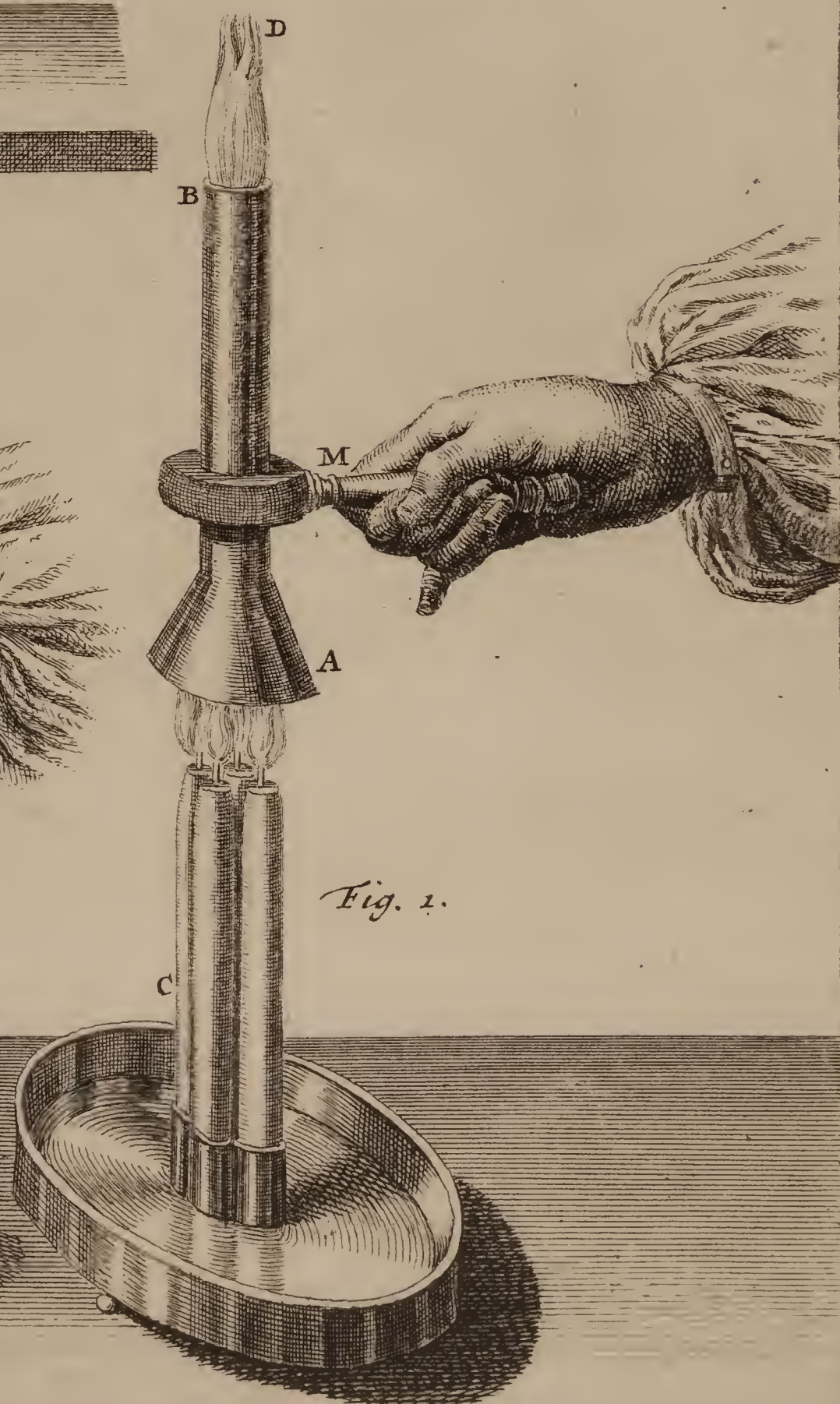


Fig. 2.



Fig. 1.



Chap. 14. *of Natural Philosophy.* 95

We also refer the Action of Water, when it extinguishes Fire, to the want of Air. 2593.

In the Combustion of those Bodies which attract Water, if this, which will not burn, because it contains no Food for Fire, be pour'd upon them, it will immediately touch or cover the Bodies in such a Manner as to hinder the Access of the Air upon which the Fire is extinguish'd, unless the Quantity of the Water be very small with regard to the Bigness and Violence of the Fire: For in that Case the Water is immediately chang'd into Vapour, and driven back. 2594.

But when the Bodies are such, that the Water will not immediately touch or mix with, as Oil and greasy Bodies, the Water will not extinguish these, unless it be pour'd upon them in such Abundance, as to take away the Access of the Air from every Part. 2595.

There are also some Fluids which, though they will mix with Water, yet, when on Fire, will not be extinguish'd by Water; which seems to contradict what has been already said *: But the Water * cannot apply itself to the Surface of these Fluids, and be dispers'd over them, as it shou'd be, to hinder the Access of the Air. 2596.

The Action of the Water upon the Fire contain'd in the Phosphorus, which has been already mention'd *, differs from the Action * spoken of here. For when the Phosphorus is well lighted, it cannot be extinguish'd by Water, and it's Light is more lively where there is no Air. 2597. 2499.

EXPERIMENT 4.

Write upon Paper with the Phosphorus, above-mention'd, and inclose it in a Receiver, out of which exhaust the Air, and the Letters will appear in the Dark more lively, than in the Air, but they disappear in a short Time. 2598.

When Fire is extinguish'd, the Heat is lessen'd, and therefore that Extinction has some Relation to Cold. 2599.

For the lessening of Heat is very often, but not always, call'd Cold, which is no other than that Diminution. 2600.

Those Parts that are not so hot as the Parts of our Body which touch them, that is, which lessen the Heat in our Bodies *, are * said to be cold; just as those Bodies are said to be hot which increase that Heat *. 2601. 2504.

Cold with regard to us is no other than the Sensation arising in us upon the lessening of the Heat in our Bodies, and in a cold Body * 2409. 2602.

* 2452. Body there is Heat * : But it is less than the Heat of our Body,
 * 2504. and therefore that diminishes this *.

2603. From these common Considerations alone, that Question is easily determin'd, *viz.* whether Cold ought to be ascrib'd to a Privation of Heat, or to the Presence of some particular Matter, just as Heat is owing to the Presence of Fire. It is very evident that the bare Absence of Fire is sufficient.

2604. But we may also put another Question, *viz.* whether it is possible to have a Diminution of Heat without a certain Sort of Matter, whose Particles we may call the Darts of Cold. To this I answer, that we have no Experiments to prove there is such a Kind of Matter, and therefore it is impossible to give an Answer to this Question, for we ought not to deny a Thing because we cannot prove the contrary. But this we know is always very certain, that from whatever cause it proceeds, the Diminution of Heat is sufficient of itself to cause Cold.

2605. I cannot deny but that there may be some subtile Particles, which, upon entering into Bodies, do either wholly or partly drive the Fire out of them. But that there are always such, where we find a Diminution of Heat, is what I said does not yet appear. For although there are Particles which do not attract Fire as the Particles of which Bodies consist, but repel it, it does not follow from thence that Heat cannot be lessen'd from some other Cause.

But in some Cases the following Experiment seems to shew that there are such Particles.

EXPERIMENT 5.

2606. Take a Mixture of Snow and Sea Salt, and put it into a Vessel, which surrounds a Glass fill'd with Water, if this Mixture be set on the Fire, the very Moment that it melts, *viz.* that it becomes hot, it does not, like other Bodies, communicate Heat to the Water * ; but the Water is immediately turn'd into Ice.

* 2504. If the Water be contain'd in a Tube, which is exhausted, the
 2607. Congelations is made with an Ebullition *.
 * 2128.

The End of the FOURTH BOOK.

Mathematical Elements

OF

NATURAL PHILOSOPHY

CONFIRM'D BY
EXPERIMENTS.

BOOK V.

PART I. Of the Motion of Light, and it's
Inflection.

CHAP. I.

Of the Velocity of Light.

WE have observ'd that the intimate Nature of Fire is un- 2608.
known to us*; this must also be referr'd to Light. We* 1392.
do indeed deduce many Phenomena of Light from a few Proper-
ties of Light, which we discover by Experiments; but it will ap-
pear from the Phenomena themselves that many Properties of
Light are conceal'd from us.

We have before observ'd that Light moves in right Lines*. 2609.
Light does not go from one Point to another, if there is any Ob-* 2414.
stacle in the right Line, which we suppose drawn between these
Points.

2610. *If Light passes through an Hole, it keeps it's Direction, and is*
 * 1744. *not dispers'd sideways, as has been said of Waves *.*

DEFINITION 1.

2611. *Any Light whatsoever consider'd with regard to the Direction of it's Motion, if it be all carried in the same Direction, is call'd a Ray of Light.*
 2612. We have seen that a Body, which emits Light, is said to be
 * 2411. lucid *.
 2613. *The Surface of a lucid Body, consists of lucid Points, which emit Rays of Light every Way.*

DEFINITION 2.

2614. *A Body is said to be transparent, through which Light can pass, the Right-lin'd Motion of the Rays, in the Body, not being disturb'd.*

DEFINITION 3.

2615. *Bodies, that intercept Light, are call'd opaque Bodies.*
 But there are two Questions propos'd with regard to the Motion of Light.
 2616. 1st. Whether the Motion of Light is to be attributed to a simple Pressure, or whether there is a Removal from one Place to another.
 2617. 2^{dly}. Whether the Propagation of Light be instantaneous, or successive.
 2618. I shall say something of the first Question. According to those, who attribute the Motion of Light to Pressure, the small Globules, which touch one another, are dispers'd through the whole Space, through which the Light is propagated. The Light appears, when by the Action of the lucid Body, the Globules next the Body are press'd, which press those next to them, and thus the Propagation is caus'd.
 2619. I shall only make one Objection to this Opinion. A Globule is surrounded by many others, and, if those are compress'd according to different Directions, they likewise press that very Globule according to different Directions; and this, that all the Rays may keep their Direction, ought to press the other Globules according to all these Directions; but this cannot be; for all the Pressures are reduc'd to one only *, and a Globe compress'd presses upon all the adjacent ones, which can resist this Pressure, whether they answer to those that press, or not; whence wou'd follow a Confusion

fion of Rays : Contrary Pressures wou'd also mutually destroy one another. But it appears from Experience that innumerable Rays pass through the smallest Hole, without any Confusion. It will be manifest from what we shall afterwards say of Vision, that this happens, when we see many Objects through a small Hole.

If the Propagation of Light be not by Pressure, it is not instantaneous ; but it is by Translation from one Place to another, in which some Time is consum'd. Although this general Observation be sufficient to answer the first Question * ; we will illustrate it * more, and examine, whether we cannot determine the Velocity of Light from Phenomena. 2620. 2617.

Cassini and *Reaumur* were the first, who attempted to determine the Velocity of Light from astronomical Observations ; the former soon chang'd his Opinion, being persuaded that the Conclusions, which he had drawn from Phenomena, did not follow from them ; because all Phenomena did not agree. *Reaumur* continued in his Opinion, and endeavoured to defend it with all his Might ; and therefore it is now attributed to him alone : I shall briefly consider it. 2621.

But as we have to do with astronomical Observations, what relates to the present Question, might be more easily and fully explained in the next Book ; nevertheless I shall undertake to explain it now, and shall mention some Things belonging to Astronomy ; but only such, as immediately relate to our Purpose ; and I shall endeavour to propose them in such Manner, that they may be understood by those also, who have not yet acquired Ideas of the Motions of the heavenly Bodies. 2622.

The Sun, the Fountain of Light, enlightens the Bodies with it's Rays, which move round it ; these Rays by being reflected become visible, as will be more fully explain'd, when I treat of Vision. Amongst these the Earth itself performs it's annual Revolution round the Sun. 2623.

The Bodies that move round the Sun, are spherical, and opaque, and are call'd Planets ; we shall take into Consideration one of these, call'd *Jupiter*. Round this there move four smaller Bodies, call'd Satellites ; which revolve circularly round the Center of *Jupiter*. 2624.

These Satellites in their Revolutions pass through the Shadow of *Jupiter*, and are eclips'd, and indeed every Revolution, if we except the fourth, which is at the greatest Distance, which sometimes passes by the Side of the Shadow.

Astronomers have chiefly taken Notice of the inmost, or least distant of them, and have observ'd it's Motion more accurately, than that of the others, in order to determine it's Immerfion into the Shadow, and it's Emerfions out of it.

2625. Let S be the Sun, A B C D the Orbit of the Earth ; I *Jupiter* in his Orbit ; E F G the Orbit of the inmost Satellite ; this paffes through the Shadow at E F. If the Body of *Jupiter*, and the Orbit of the Satellite, fhould have a Magnitude proportioned to this Figure, they cou'd not be perceiv'd.

Pl. 85. F. 1.

2626. The Computations would be very fimple, if, whilst the Satellite is carried equably in a Circle round *Jupiter*, in the periodical Time discover'd, this turn'd about the Sun in the fame Manner ; but this is not the Cafe ; whilst the Shadow turns about with *Jupiter*, it will not move equably, and in refpect of that the Computation must be corrected ; this Correction is call'd *the first Equation of the Satellite*. Moreover we ought to have regard to the Time the Satellite remains in the Shadow, which is greateft, when the Satellite paffes through the Center of it, and different according to the different Distance from the Center, at which it paffes along. From these Observations made accurately, the Moment of the Beginning or End of the Eclipse may be determin'd.

2627. But this Computation is not fufficient, in the Observation of an Eclipse ; the Observation differs more or lefs from the Computation, according to the different Situation of the Earth with refpect to *Jupiter* ; and the greateft Difference wants little of a Quarter of an Hour.

But it is manifest, that the Situation of the Earth does not alter the Eclipse ; and that therefore this Retardation must be attributed to an extraneous Cause.

2628. When the Earth paffes between *Jupiter* and the Sun at A, the Computation mention'd agrees with the Observations ; but when the Earth recedes more from *Jupiter*, a fecond Correction, which is call'd *the second Equation*, is to be made use of. This Equation follows the Ratio of the Increase of the Distance of the Earth from *Jupiter*, whilst the Earth moves through A B C ; and the Eclipse is retarded in the Ratio of this Increase of the Distance, meafur'd in a right Line drawn to *Jupiter* ; and in the fame Manner is diminish'd the Retardation in the Motion of the Earth through B D A, in which it draws nearer to *Jupiter*.

2629. This Proportion was the Reason, that *Reaumur* attributes the Delay taken Notice of to the Motion of Light, and the Conclusion is evident ;

evident; for if at the very Moment, when the Satellite goes out of the Shadow, it is visible at any Distance whatever, it matters not whether a Spectator be at A, or B, or at a greater Distance from *Jupiter*, he will perceive the going out from the Shadow at the same Time, and the second Equation which has been mention'd cannot take Place; but as it really does obtain, it is no Wonder that this Invention has been, as it were, universally approv'd of.

The first, who denied that this second Equation of the Satellites was to be attributed to the successive Motion of Light, was *Cassini* himself, who had found out with *Reaumur* that an Equation was to be made use of in the Computation. His Reason for it was this; he perceiv'd that a like and equal Equation, ought also to take Place with regard to the other Satellites, if it really depended upon the Motion of Light; he discovered indeed a like Equation, but what was much greater, with regard to the other Satellites, and different in every one.

2630.

The Opinion of *Reaumur*, which was oppos'd by a celebrated Astronomer, shortly had a celebrated Defender. Dr. *Halley*, who contracted *Cassini's* Tables, relating to the Motion of the inmost Satellite, and rendered the Computation more easy, made some Observations, from which it follows that the second Equation is the same with regard to the third and fourth Satellite, as the first; and thus, having remov'd the Difficulty propos'd by *Cassini*; he remov'd the Objection made to the Argument of *Reaumur* for the successive Propagation of Light.

2631.

It is no Wonder, if the Conclusions from different Observations do not agree: The second Equation is discover'd by comparing the Computation with the Observations; but the Computation is founded upon the Tables, made for that Purpose, and who will affirm that these are accurate enough to solve the Question? And it will appear presently that this Objection was not without Reason.

2632.

What has been hitherto said, regards the last Age, but the Dispute was not ended with the Age; *Maraldi*, Astronomer of the Academy of Sciences, in the Year 1707, oppos'd the Opinion of *Reaumur* with new Arguments, and endeavour'd to add new Force to *Cassini's* Arguments, by taking Notice of other Observations, from whence it follows that the second Equation should be greater in the remote Satellites than in the first.

2633.

But the chief thing relates to a more accurate Observation of the first Satellite; with regard to which he observes, that a certain third Equation is neglected, which might arise to three Minutes and an half,

half, and which would be to be consider'd, if, what was said of the Velocity of Light, was true.

2634. *Jupiter* describes an Ellipse about the Sun, in one of whose Foci is the Sun's Center; which the Point is in the Ellipse we have

* 625. seen above *. The greatest Distance of *Jupiter* from the Sun exceeds the least by a Quantity equal to the half of the Distance S A of the Sun from the Earth; and the Distance of *Jupiter* from the Earth may be increas'd by such a Quantity, by Reason of the said elliptical Figure; for S I increasing, the Distance of *Jupiter* from the Earth is increas'd, in whatsoever Part of it's Orbit it be; and the Retardation of the Eclipse would increase according to the Ratio of this Increase, if the Reasoning of *Reaumur* should obtain *.

* 2629. But *Maraldi* takes Notice of some Observations, which differ
2635. very little from the Computations, and which would sensibly err from them, if this last mention'd Increase of the Distance of *Jupiter* shou'd be taken Notice of. From whence he concludes, that the Equation last mention'd, is not to be receiv'd in the Tables, and that *Reaumur*'s Opinion is to be rejected.

2636. But *England* has produc'd a second Defender of this Opinion.

It appearing from many Observations, that, the first Satellite mov'd a little faster than according to *Cassini*'s Tables, *J. Pound* thought upon correcting those Tables, who had made many accurate Observations upon *Jupiter*, and the other heavenly Bodies. But the Error of the Tables is so small, that it cou'd not be discover'd but after many Years.

2637. But this Astronomer affirms, that it appear'd to him from many Year's Observations, that the second Inequality is the same in all the Satellites. And having corrected *Cassini*'s Tables of the first Satellite, which he delivers as more accurately agreeing with the Heavens, he added the third Equation, which *Cassini* omitted, *Halley* had taken Notice of, and *Maraldi* had said ought to be re-

* 2635. jected *. It is not to be wonder'd at, that Astronomers shou'd not agree together; we are considering an intricate Matter, and

* 2632. which is not immediately deduc'd from Observations *: Therefore that might be attributed to one Cause, which shou'd have been attributed to another, and the Error might not be discover'd but by comparing the Observations made at different Times; so that the Difficulties cou'd be remov'd only after a long Time; in the mean Time there was always something obscure, which was at length remov'd by the great Astronomer last mention'd. This Obscurity was the Reason that *Reaumur* himself, had deduc'd from his first Observations,

Observations, that the second Equation might increase to twenty two Minutes, when the greatest in *Cassini's* Tables is fourteen Minutes.

Now if this second Equation be ascrib'd to the Motion of Light, to this we ought to attribute the Velocity, with which it comes to us from the Sun in seven Minutes Time.

2638.

But the Velocity of Light is not deduc'd from Observations made on the Satellites of *Jupiter* only. A few Years ago Mr. *Bradley*, Professor of Astronomy at *Oxford*, demonstrated the Motion of Light from Observations made upon the fixt Stars, at first jointly with *Molineux*, and which after his Death *Bradley* prosecuted alone, to whom also we owe the Conclusions concerning the Motion of Light, whose Velocity he determin'd, which did not differ much from that, which we have mention'd *.

2639.

* 2638.

In order to understand the Force of the Argument, upon which this Conclusion depends, some Things must be premis'd.

The fix'd Stars are lucid Bodies, and are at Rest with regard to the planetary System, from which they are very remote. In this planetary System, the Earth takes it's Place among the Planets, and moves round the Sun, which is at Rest, as has been said *.

2640.

* 2623.

Let us suppose the Sun to be represented at S; the Circle A B C D to represent the Way of the Earth round it; and this to be in the Plane, through which the Center of the Sun passes, and is call'd the Plane of the Ecliptick. Let us suppose in this Center a Perpendicular to this Plane to be rais'd, which we suppose to be represented by S P, and to pass through any fixed Star. It is no Matter whether or no there really be a Star in the Heavens in this Perpendicular; we shall reason, as if it were so, and this will answer our Purpose.

Pl. 85. F. 2.

If a Spectator should be at S, he would see the Star in this very Perpendicular; but if the Spectator shou'd run through the Circle A B C D, and the Diameter of it shou'd have a sensible, though small Ratio to the Distance of the Star, this will seem to alter it's Situation in the Heavens. The Spectator at A wou'd see the Star along the Line A P a; being plac'd at C he would see it along the Line C P c; and in the same Manner every where; wherefore the Star would seem to run through the small Circle, represented at a b c d.

2641.

If the Distance of the Star shou'd be so great, that in respect of it the Diameter A C, of the Earth's Orbit, might be looked upon as a Point, in which Case the small Circle mention'd wou'd be entirely insensible, all the Lines, drawn from Points of the Orbit to the

2642.

the Star, might be looked upon as perpendicular to the Plane of the Ecliptic, and would answer, as to Sense, to the same Point in the Heavens, with the Perpendicular at S; in which the Star wou'd always appear; if Light came to us in an Instant, as was suppos'd in the foregoing Reasoning *.

* 2640.

2643.

But if in this Case, in which the Star is so remote, we suppose, the Light to be propagated from the Star with a certain Velocity, whilst the Earth runs through it's Orbit, a Spectator will see it in a Direction oblique to the Plane of the Orbit, by Reason of the Motion compounded of the Motion of the Light and that of the Spectator.

2644.

Plate 85.

Fig. 3, 4.

Let us suppose the Light to be mov'd along the Line EG , making any Angle with the Line FG , in which the Spectator is carried, whom we suppose at F ; let the Velocity of the Spectator be to the Velocity of Light, as FG to EG . Whilst the Spectator runs through FG , the Light moves through EG ; and the Particle of Light, which is at E , when the Spectator is at F , enters the Eye, when it comes to G ; but the Direction of the Light with regard to the Eye makes the Angle EFG with the Line FG . For if we suppose the Line FE drawn, and carried with a Motion parallel with the Eye, so as with respect to that to be at Rest, whilst the Eye is mov'd, the Light will enter into the Eye in this Line; for when the Eye shall be at f , in the Middle Point between F and G , the Line mov'd will cut EG in it's Middle Point g , which the Particle of Light has arriv'd at, which is also the Middle Point of the Line mov'd fe ; therefore the Point of Light, which was at E , at the End of the Line EF , has come to the Eye along eg ; and will enter the Eye in this Direction.

2645.

Fig. 3.

Now let the Angle EGF be a right one, and let EG be to FG , as the Velocity of Light to the Velocity of the Earth in it's Orbit, and EFG will be the Angle, which the Direction, according to which the Light enters into the Eye, makes with the Plane, in which the Earth moves round the Sun.

2646.

Pl. 85. F. 5.

* 2642.

If the Earth be at B , it moves in the Direction of the Tangent to the Orbit in this Point; that is, if we bring the Spectator to S *, the Direction of the Motion of the Earth is along SC ; and, making the Angle aSC equal to the Angle EGF of the third Figure, the Line Sc will represent the Line, along which the Spectator wou'd see the Star. In the same Manner when the Earth shall be at D , the Spectator being brought to S , will see the Star along Sc , supposing the Angles PSc and PSa to be equal; and

and this Line Sa , or Sc , wou'd, by it's Revolution round PS , describe a Cone, whose Base in the Heavens wou'd be a Circle run through by the Star in a whole Year, with it's apparent Motion: Let us suppose this Circle to be also represented by $abcd$, supposing the Letters to be as in the second Figure.

If the Star shou'd not be in the Perpendicular PS to the Plane of the Ecliptick, but if the Line PS shou'd be inclin'd to this Plane, the Lines which determine the apparent Motion of the Star in the Heavens, wou'd make Cones, as in the Cases explain'd *; but these wou'd now be oblique, and in each Case the apparent Way of the Star in the Heavens wou'd be determin'd according to what has been explain'd; but it wou'd be elliptical, and the greater Axis of the Ellipse * wou'd be equal to the Diameter of the Circle $abcd$, of the second Figure, or the fifth; so that from the Ellipse being known there is given the Circle, which the Star wou'd describe, if it shou'd be in the Perpendicular to the Plane of the Ecliptick.

It is to be determin'd from Observations, whether the Stars do describe such Ellipses; and in these are great Difficulties, which nevertheless the Reverend Mr. *Bradley* has overcome by his Labour, and incomparable Industry.

Nothing can be immediately determin'd concerning the elliptical Motion which has been mention'd. The Distance of a Star from the Pole of the World, at different Times of the Year, must be measur'd; and from the different Distances, the elliptical Motion must be determin'd by Computation, attending to the Motion of the Pole itself in the Time, which passes between the Observations; for the Pole moves in a smaller Circle, in which it runs through one Degree in seventy Years.

Mr. *Bradley* having taken all necessary Cautions observ'd many Stars at different Times of the Year, and immediately discover'd that their Distances from the Pole of the World varied; and he perceiv'd that this Variation cou'd not be attributed to the Nutation of the Pole; for he examin'd two Stars equally distant from the Pole, but opposite in such Manner, that one ought to have receded from the Pole, so much as the other approached towards it, if the Pole itself had been mov'd. But this did not happen; the Alteration with respect to one Star was double of that, which the other Star underwent, always setting aside the Motion of the Pole from it's Revolution which has been mention'd.

2651. This diligent Observer, deduc'd from Observations, that the Stars, at stated Times, receded from the Pole of the World, and approached towards it, according to the Law which the above-mention'd Motion in an Ellipse requires * : And indeed in such Curves, from which with regard to all is deduc'd the Motion in the same small Circle, as $abcd$, when the Stars are brought to the Perpendicular at S to the Plane of the Ecliptick *; and the Diameter of the Circle with regard to all the Stars is $40'' \frac{1}{2}$.
2652. But when this appears from Observations, these easily shew, to which of the two Causes above-mention'd we ought to attribute the Motion of the Star *. For if the first shou'd take Place, the Motion of the Star wou'd be from a to c , whilst the Earth runs through the Part ABC of it's Orbit *; but this disagrees with Observations, and this Cause does not take Place. But this Alteration in the Situation of the Star, according to Observations, obtains whilst the Earth runs through the Part of it's Orbit BCD, as the second Cause requires *.
2653. If the two Causes shou'd take Place together, the Arch, run through by the Earth, wou'd differ from the two above-mention'd; and the Concourse of the two Causes also disagrees with Observations; unless we wou'd attribute to the first Cause, some small Matter, that is not sensible in Observations. From all which we deduce the following Conclusions.
2654. 1st. That only the second Cause takes Place here; and that the Distance of the Stars is so great, that the Diameter of the Earth's Orbit has no sensible Ratio to it *.
2655. 2dly. That the Angle FEG, in the Triangle above-mention'd *, is $20'' \frac{1}{2}$; and therefore there is the Ratio of 10210 to 1, between EG and FG, that is, between the Velocity of Light and that of the Earth's in it's Orbit. Whence it shou'd follow, that Light comes to us from the Sun in eight Minutes and an half.
2656. 3dly. That Light comes from all the Stars with the same Velocity; for the Angle EFG is the same with respect to all. Whence it follows (if we suppose, that the Stars are not all at equal Distances from us, as many Arguments shew) that the Motion of Light, whilst it passes through immense Spaces to our Atmosphere, is equable.
2657. But we must attend to this, that the small Differences cannot be perceiv'd; and no one can deny, that, in the Measure of a small Angle, whatsoever Care we take, there may easily be an Error of one Second; and therefore, although we said that the first Cause

was

was to be rejected *, we do not deny that the Stars from this Cause * 2652.
describe a small Circle perhaps, whose Diameter is equal to 1",
or exceeds this Measure a little.

We have in this Chapter examin'd what relates to the Velocity 2658.
of Light, with the greater Care, and the more clearly; because all
that is demonstrated in the following ones, depends upon this Foun-
dation; viz. that the Motion of Light is successive, and that it
may be accelerated, and retarded, in the passing of Light from one
Body to another.

C H A P. II.

Of directing the Sun's Rays.

THE Motion of the Rays being demonstrated, we must en- 2659.
quire into the Properties of them, that we may deduce Phe-
nomena from them. For this Purpose the Sun's Rays must be con-
sider'd. But in this Examination we meet with two Inconve-
nencies, of the Method to remove these I shall speak in this Chap-
ter. The Inconveniencies are these, 1. The Obliquity of the
Rays; 2. The continual Motion of the Sun.

From the Obliquity of the Rays it follows, that some Experi-
ments can only be made at certain Hours; and others can never be
made in a Place, otherwise convenient, although it be large enough,
and expos'd to the Sun's Rays, a great Part of the Day. By the
Motion of the Sun the Direction of the Rays is continually alter'd,
so that the Constitution of the Machines, made use of in the Ex-
periments, must be continually alter'd.

By making use of the following Machine, both Inconveniencies
are remov'd.

A N H E L I O S T A T E,

Whereby the Sun's Rays are fix'd.

This Machine consists of two principal Parts, each of which 2660.
consists of many smaller Parts. The first is a plane metallick Spe- Plate 83.
culum, supported by a Stand, the other is a Clock which directs
the Speculum.

We make use of a metallick Speculum, because there is a dou- 2661.
ble Reflection in a Glass one. The Magnitude and Figure of it

are not material ; mine is rectangular, four Inches long and three broad.

This is put into a wooden Frame, which is furrounded with wooden Rulers, cut in, whereby the Speculum is retain'd.

2662. To sustain this, without hindering it's Motion, to the said wooden Frame, behind, is applied the Brass Plate *aa*, whose Ends, being bent, are fasten'd to the Wood sideways.

2663. This Speculum *S* is suspended by the Handle *AA*, small Screws being put through Holes in the End of it, which go into the Ends *a, a*, of the said Frame, and whose Parts, which are in the Holes of the Handle, are cylindrical, so that the Speculum turns freely upon it's Axis, which, if it were made sensible, wou'd pass along the Surface of the Speculum.

2664. The Handle is join'd to the Cylinder *C*, whose Axis, if it were continued, wou'd concur with the middle Point of the said Axis of the Revolution of the Speculum.

2665. To the same Point answers the Tail *DE*, which is join'd perpendicularly to the hind Part of the Speculum. This Tail is cylindrical ; and is made of a Brass Wire, which is strait, firm, and whose Diameter is about a sixth Part of an Inch.

2666. The Cylinder *C* is put upon the wooden Stand *P*, whose upper Part is represented by itself ; whilst this is done, the Iron Cylinder *e*, whose Surface is smooth, goes into a Cavity in the Cylinder *C*, which is of Copper ; by which Means this turns freely about it's Axis, so that, by the Motion of the Tail *DE*, the Position of the Speculum is very easily alter'd as you please.

2667. This is rais'd, and depress'd, by Means of the three Brass Screws *B, B, B*, which are turn'd with a Key, and go through a Plate of the same Metal, which is applied to the Bottom of the Stand for that Purpose ; and which stands out in three Places, to receive the Screws.

2668. If the Speculum is to be rais'd higher, as may easily be done, we put the Speculum together with it's Stand, upon a small Board, which has low Feet, and is made for that Purpose.

2669. The other Part of the Machine is a Clock, as has been said above. This is represented at *H* ; the Index performs it's Revolution in twenty four Hours.

2670. The Plane of the Clock is inclin'd to the Horizon, according to the Inclination of the Equator in the Place, where the Machine is made use of ; that is, in this our City of *Leiden* is $37^{\circ} 49'$.

Chap. 2. of Natural Philosophy.

109

But this Machine may be made use of in other Places, whose Latitudes differ one or two Degrees from this Place, as will appear *.

2671.

* 2675.

2672.

The Clock is sustain'd by the Copper Pillar F G ; this consists of two Parts, which are joined by the Screws d, d , between which, as in a Sheath, is mov'd an Iron Plate, in the Middle of which there is a Slit, through which the said Screws d, d , pass. This Plate is join'd fast to the lower Plate of the Clock itself, which is rais'd and depress'd by this Method, and fasten'd by the Screws d, d . It may also be rais'd higher by the Screws I, I, I, which go through the thick Copper Plate L L M, upon which the Pillar F G stands.

The extreme Parts of this Plate L, L, are terminated in such Manner, that bc and cb make one right Line, through which we suppose a vertical Plane to pass, this will be perpendicular to the horizontal Lines, which may be drawn on the Plane of the Clock ; such as are fg, bi .

2673.

The Machine is so order'd, that the Plane of the Clock may have the Inclination beforemention'd *, when the Plane L L M * is horizontal ; in which Situation it is easily plac'd by Means of the Screws I, I, I, by Help of the Plumb Line Q, whose Point shou'd answer to the Point o , which is mark'd upon the Surface L L M.

2674.

2670.

If the Machine were to be us'd in another Place, whose Latitude differ'd from that, for which the Machine was constructed *, another Point as o wou'd be to be mark'd, in which Case the Plane L L M wou'd be inclin'd to the Horizon.

2675.

* 2671.

The Axis of the Wheel, which moves the Index, is pretty thick, and is perforated cylindrically ; but the Cavity inclines a little to a conical Figure ; for towards the Bottom it is somewhat narrower.

2676.

The Index itself is represented at ON ; this is of Brass, and it's Tail $p q$ exactly fills the Cavity mention'd last, into which it is thrust tight, that it may stick, and, that the Wheel may carry the Index with it as it moves ; whose Situation may yet be alter'd, and set to any Hour.

2677.

This Tail has also a cylindrical Hole, and through this passes the small Brass Wire ld , which remains in any Situation, whilst it is rais'd, or depress'd.

2678.

At the End O of the Index there is a small Cylinder n , which is perforated cylindrically.

2679.

The

2680. The Length of the Index is measur'd in the Line, perpendicular to ld , drawn from the Axis of the Cylinder n to the Axis of the Wire ld . In my Machine this Length is fix Inches.
2681. The Iron Tail t of the Piece T goes into the Cavity of the Cylinder n ; this Tail exactly fills the Cavity, but yet moves freely in it.
2682. Between the Legs of the Piece T, the small Pipe R may be suspended at different Heights, through which the Tail DE of the
- * 2665. Speculum may be mov'd freely *, which fills the Pipe very exactly.
- † 2663. This small Pipe is suspended, as was said of the Speculum †. The small Screws r, r , pass through the said Legs, and the Ends of them go into the Parts m, m , of the Pipe, and remain there: Then the Pipe turns freely about the Axis which passes through mm ; for the Parts of the small Screws are cylindrical, which answer to the Holes in the Legs of the Piece T.
2683. When the Machine is to be fix'd, we make use of another Machine which we shall call a *Placer*.
2684. The Cylinder C together with it's Speculum is remov'd from the Stand P, upon which is plac'd the Brass Pillar V X. This sticks tighter to e than the Cylinder C, that the Pillar may keep it's Place, whilst the Machine is settled.
2685. Upon the Head X the Ruler Y Z moves round a Center, so that it may be inclin'd to the Horizon as you please, and keep it's Position. The Length of the Arm Y X is determin'd at Pleasure. The Arm X Z is of a peculiar Construction, and a certain Length.
2686. To the said Ruler, which is not extended beyond y , there are applied to others, as $x Z$, between which the first is inclos'd: These are join'd at Z, and also cohere by Means of the Screws z, z , which pass through a Slit in the first Ruler. On this Ruler is mark'd the small Line vs , whose Length is equal to nine hundredth
- * 2680. Parts of the Length of the Index *; and which is divided, in the Manner which will be mention'd presently.
2687. The Arm X Z is equal to the Length of the Index *, if it be
- * 2680. measur'd between the Center of Motion at X and the End Z, when the End x of the outward Ruler, agrees to v , where the Divisions of the small Line vs begin.
2688. The Divisions of this small Line are unequal, and determine the Length of the Arm at different Times of the Year, by applying x to the Division, which answers to the Day, in which the Machine is us'd.

Chap. 2. of Natural Philosophy.

III

But in order to mark the Divisions, we suppose the Length of the Arm * to be divided into a thousand equal Parts, that is, $v s$ * into ninety Parts; but the Distances from the Point v are set down in the following small Table.

21. Mar.	1. Mar.	21. Fe.	11. Fe.	1. Fe.	21. Ja.	11. Ja.	21. Dec.	2689.
0.	8.	17.	32.	47.	64.	77.	90.	
21. Sept.	11. Oct.	21. Oc.	1. No.	11. No.	21. No.	1 Dec.	21. Dec.	2680.

On the opposite Side of the Ruler, there is also drawn a small Line, which accurately answers to $v s$, whose Divisions are contain'd in this second small Table.

21. Mar.	11. Ap.	21. Ap.	1. May	11. May	21. May	1. Jun.	21. Jun.	2691.
0.	11.	22.	36.	51.	66.	79.	90.	
21. Sep.	1. Sep.	21. Au.	11. Au.	1. Au.	21. Jul.	11. Jul.	21. Jun.	

These Things being thus order'd, to fix the Machine, it is put upon a Plane that is horizontal, or nearly so. 2692.

First we join the Placer * to the Stand $P \dagger$, which we raise as much as is necessary *, that the Ruler $Y Z$ being reduc'd to a just Length $\dagger$, which we turn at Pleasure, and incline, in every respect, that is with respect to the Place, and Direction, may agree to the Sun's Ray, which we undertake to fix. * 2667. 2668. $\dagger$ 2688.

We so order the other Part of the Machine, that the Lines $b c$, $b c$, may agree to a Meridian Line, which has been drawn on the Plane *; and it is so dispos'd by Means of the Screws I, I, I , * that the Plumb-Line Q may answer to the Point $o \dagger$. 2694. $\dagger$ 2674.

The Index $N O$ is turn'd *, that the Sun's Rays may pass directly through the Pipe $R \dagger$, which is turn'd, and inclin'd, as is requir'd. The Brass Wire $l d$ * is then rais'd or depress'd, that the Shadow of the End of it l may pass through the Middle of the Pipe. * 2677. $\dagger$ 2682. * 2678.

This whole Part is mov'd to the Placer, which is order'd as has been said before *. But the Clock is so mov'd towards the Placer, and rais'd, that the End l of the Brass Wire $l k$ may agree to the End Z of the Ruler $Y Z$. 2696. * 2693.

We must continually have regard to the Plummet Q , that it may always answer to the Point o ; we must also take Care, that, after the Clock is mov'd, the Sun's Rays and the Shadow of the Point l , may pass through the small Pipe R , as before, that the Position with respect to the Meridian may not be disturb'd.

The

2697. The Pillar V X with it's Ruler Y Z is remov'd, the Stand P being left in it's Place, on which the Cylinder C, with it's Speculum, is put. The Piece T is taken out of it's Place, that the Tail D E of the Speculum may be put through the Pipe R ; when the Piece T is put in the same Place again, every thing is ready.

2698. Then the Rays reflected from the Middle of the Speculum, to which all the other Rays, reflected from the Speculum, are parallel, agree, as to Place, and Direction, with the Position which the Ruler of the Placer had ; and whilst the Tail of the Speculum is mov'd, as the Clock moves, whose Index follows the Sun, it's Situation is alter'd with respect to the Sun ; but the Ray, reflected from the middle Point of the Speculum, remains fix'd.

2699. If, the Index N O being taken away, we substitute the Index K, the Machine may be us'd as a common Clock.

2700. The Experiments concerning Light must be made in the Dark ; for this Reason the Machine, when made use of in the Experiments, must be shut up in a Box or Case.

A B O X or C A S E,

In which the Helioslate is inclos'd.

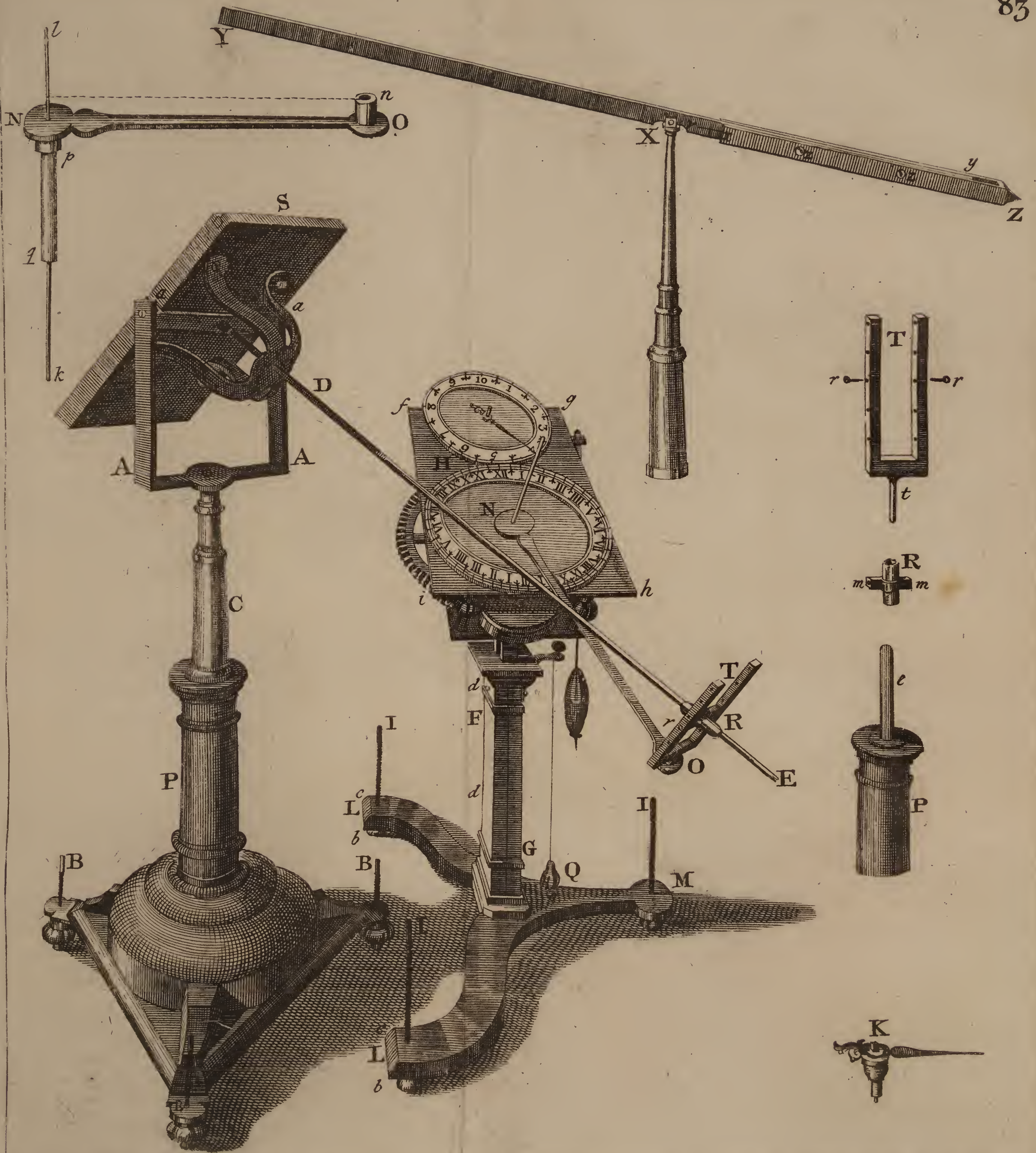
2701. The Box is represented at A ; it stands upon Feet, that have Plate 84. Rollers join'd to them, that it may be easily mov'd. It is open at one End, which End is mov'd to a Window, through which the Sun's Rays come freely to the Speculum.

2702. But the Box is every Way larger than the Window, that by being applied close to the Wall, the Light may be hinder'd from entering into the Chamber ; to this End, the Box is mov'd as near the Wall as possible, and the Screws C, C, which are fasten'd to the fore Feet, are turn'd, till they touch the Ground.

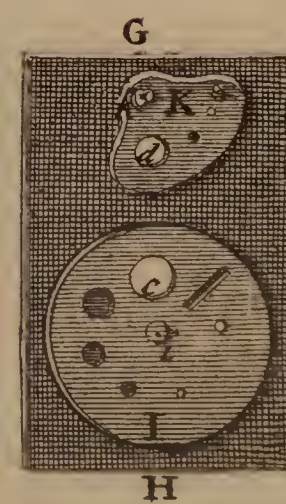
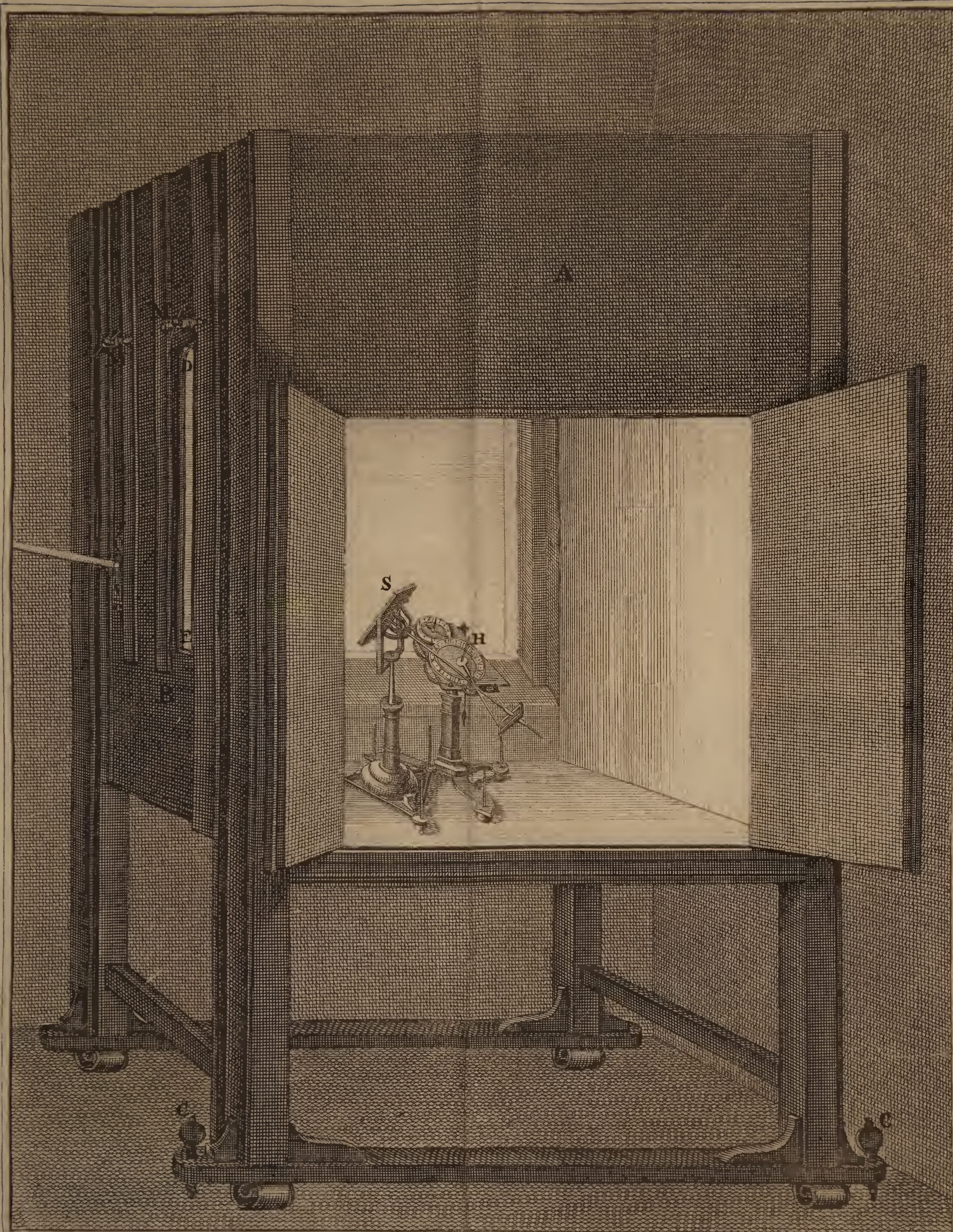
2703. The Door in my Machine is opposite to the Window ; it might have been otherwise dispos'd. We transmit the Rays through the fore Part B ; we make choice of this, by Reason of the make of the Place, in which the Experiments concerning Light were made. In this Part there are two Apertures three Inches broad, and about eighteen Inches high, one of which is represented open at D E.

2704. These are clos'd, on the Outside, by Pieces of Wood, which are moveable between wooden Rulers. Each Piece serves either Aperture, that they may be chang'd. One of them F is three Foot long, and has a Hole in it's Middle. The Aperture *ab* is five Inches long, and two broad.

This







Chap. 2. *of Natural Philosophy.*

113

This is clos'd by the Copper Plate GH, in which there are two Holes, *c*, *d*; the Diameter of that is two Thirds of an Inch, the Diameter of this is less. These Holes are stopp'd by the Plates I and K, which are applied to the first Plate GH, and are moveable about the Centers *i* and *k*: the Magnitudes of the Holes may also be varied, by turning the last Plates, as the Figure shews.

2705.

The Board F is hollow'd behind, in order to receive the object Glass of a Telescope of sixteen, twenty, or five and twenty Feet, according to the Magnitude of the Place, in which the Experiments are made; the Center of this Glass ought to answer to the Center of the Hole *c*.

2706.

This Board F is pretty long, the Holes of the small Plate may answer to any Part of the Aperture of the Box, the other Part of the Aperture remaining shut. For this Reason the second Board is shorter, it is sufficient if the Aperture be clos'd with this. These Boards are fasten'd by the Screws M, M.

2707.

We have shewn how the Box is to be applied to the Window *; but this cannot be done thus, if we wou'd make the Experiments * in the Hours, in which the Sun's Rays enter the Window very obliquely; in this Case, that the Rays may come to the Speculum, the Box must answer to a Part of the Window only; the remaining Part is clos'd any other Way; I make use of a Curtain, to exclude all the Sun's Rays.

2708.

2702.

SCHOLIUM.

A Demonstration of the Effect of the foregoing Machine.

THIS Demonstration is deduc'd from the diurnal Motion of the Sun; therefore those, who are unacquainted with the Laws of this Motion; may pass over this Scholium, till they read in the following Book what relates to this Matter.

2709.

Let S be the middle Point of the Speculum; SA the reflected Ray, which is to be kept in this Situation, taken at Pleasure; let the incident Ray, in any Moment whatever, be BS. When I speak of the Reflection of Light, I shall demonstrate, that these two Rays are in a Plane, perpendicular to the Plane of the Speculum, and that the Line perpendicular to this Plane at S, divides the Angle BSA into two equal Parts. Therefore taking SA, SB equal, and drawing BA, if this be divided into equal Parts at R, SR will be the said Perpendicular *; and this being * continued Sr shews the Position of the Tail of the Speculum *, in the * Case which we are considering.

2710.
Pl. 85. F. 8.

3. El. 3.
2665.

If the incident Ray be CS , we discover the Position of the Tail of the Speculum in this Case after the same Manner, taking SC equal to SA , and drawing AC ; for if we divide this into two equal Parts at E , and ESe be drawn, Se will determine the Position of the Tail of the Speculum.

In like Manner, supposing DS to be the incident Ray, let DS be equal to SA , and let DA be divided into two equal Parts at I ; if ISi be drawn, Si will shew the Position of the Tail of the Speculum.

After the same Manner, when the incident Ray is alter'd at Pleasure, is discover'd the Position of the Speculum, that the reflected Ray may remain.

2711. The Sun in it's diurnal Motion describes the Equator, or a Circle parallel to it; we consider this last Case.

Drawing Lines from all Points of this Circle to the Center of the Earth, these will make the Surface of a right Cone, which alters every Day; we take into Consideration any one of these Cones.

2712. Any Point on the Surface of the Earth may be taken for it's Center, by Reason of the immense Distance of the Sun; as is done in Dialling.

2713. Therefore let S be the Center of the Earth; the Rays SB , SC , SD , together with all the intermediate ones, will make a right Cone; all these being continued, and taking Sb , Sc , Sd , equal to one another and the first Lines, and therefore to SA , the Points b , c , d , will be in the Circumference of a Circle, whose Plane is parallel to the Plane of the Equator.

2714. Continue AS to a , and make Sa equal to AS ; and drawing the Lines da , ca , ba , the Line da will be parallel and equal to AD , by Reason of the Triangles ASD and aSd , which agree in every Thing*; and the Line IS continued will cut ad in the middle Point i . In the same Manner e and r divide the Lines ca , ba , into equal Parts.

2715. These Lines da , ca , ba , with the others, which are drawn from Points of the Circumference dcb to a , make the Surface of an oblique Cone. If this be cut by a Plane, parallel to it's Base, the Section will be a Circle; but if the Section passes through one of the Points, as i , e , r , it will pass through all, which easily appears; and all these Points, with the like Points, are in the Circumference of a Circle, whose Plane is also parallel to the Equator.

2716. Divide Sa into two equal Parts at l ; and draw il , el , rl , these will be parallel to the corresponding Lines, passing through S ; rl is parallel to bSB , for the Sides Sa , ba , of the Triangle Sba are bisected at l and r .

So likewise el is parallel to cSC ; and il is parallel to dSD ; and so of the others. But as bS is equal to Sa *, rl will be equal to la , or lS .

2717. When the Direction of the Sun's Rays is BS , or lr , which are parallel*, the Point S reflects the Ray along SA , when the Tail of the

* 2716. Speculum passes along r †. This Tail ought to pass along e , if the Direction

† 2710.

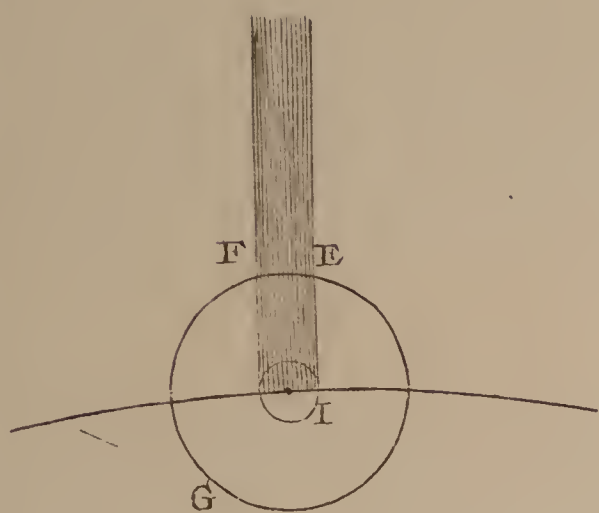


Fig. 1.

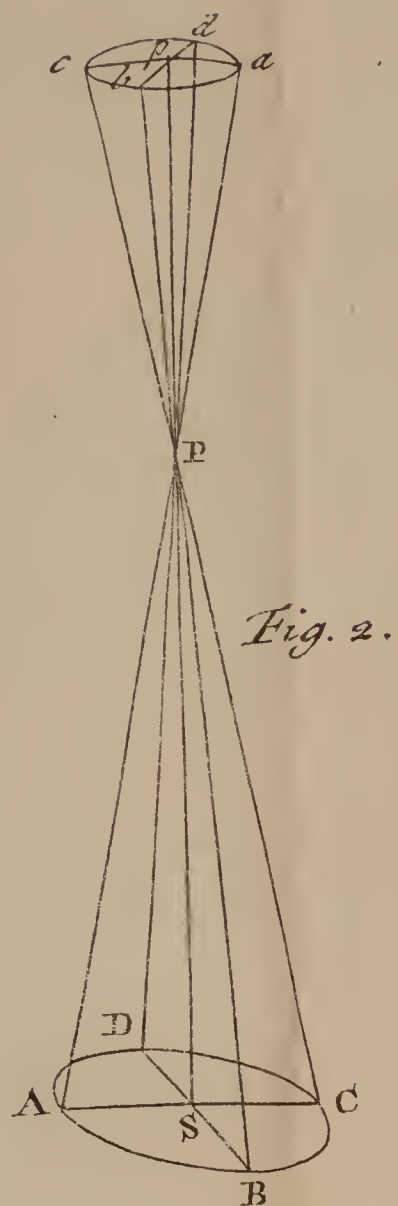


Fig. 2.

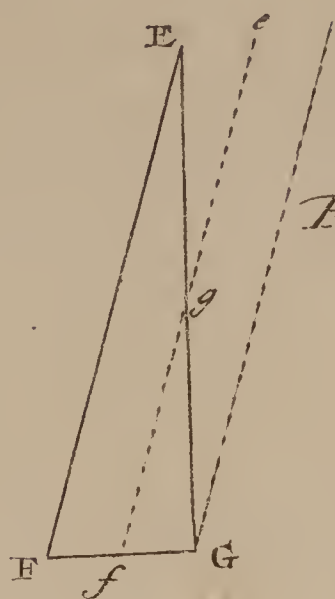


Fig. 3.

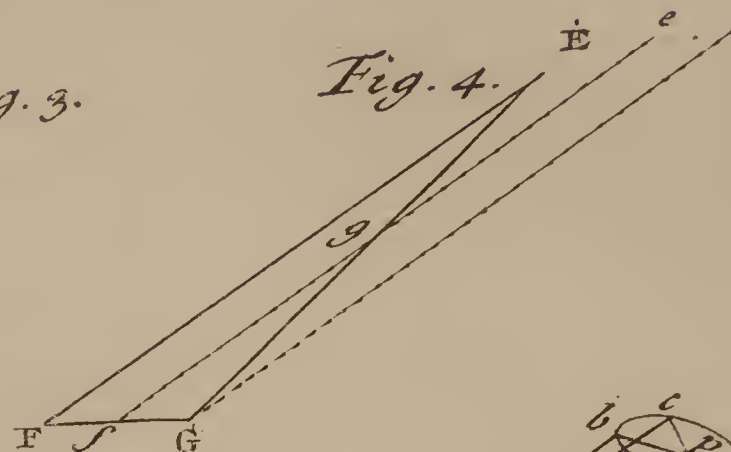


Fig. 4.

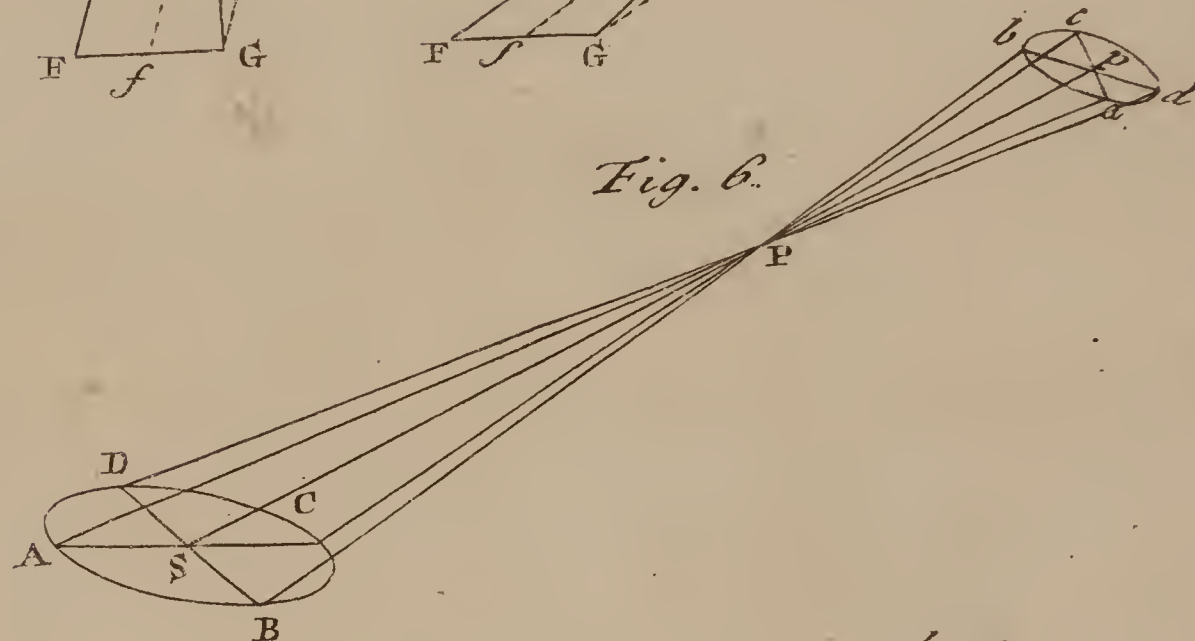


Fig. 6.

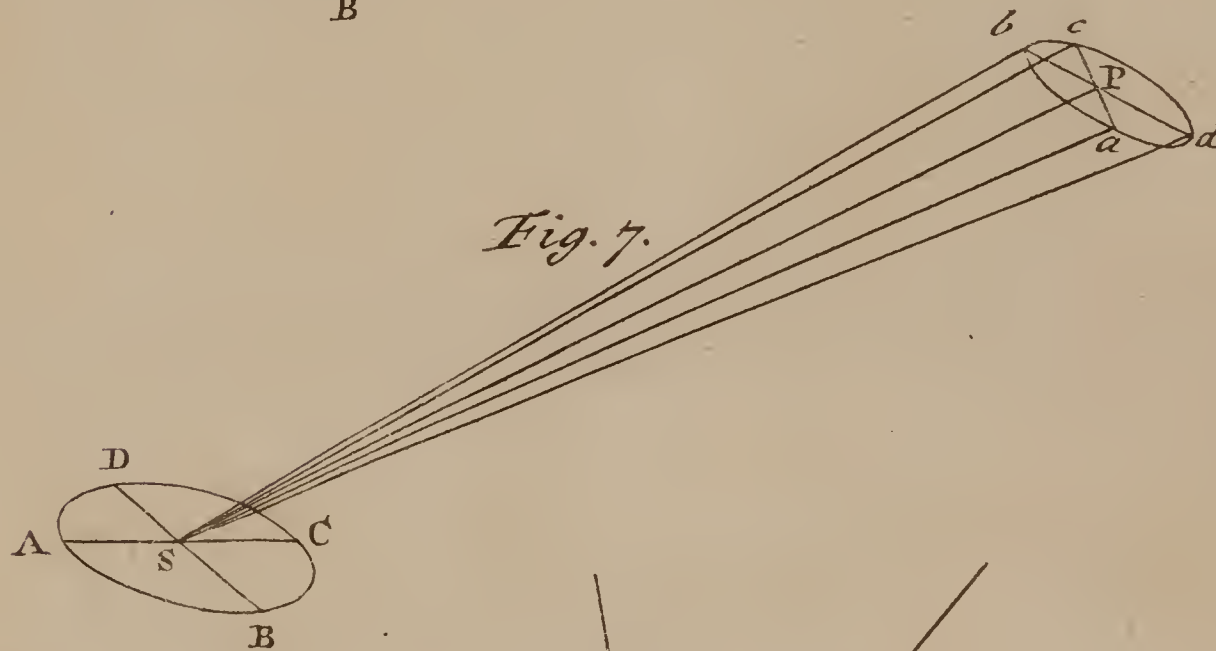


Fig. 7.

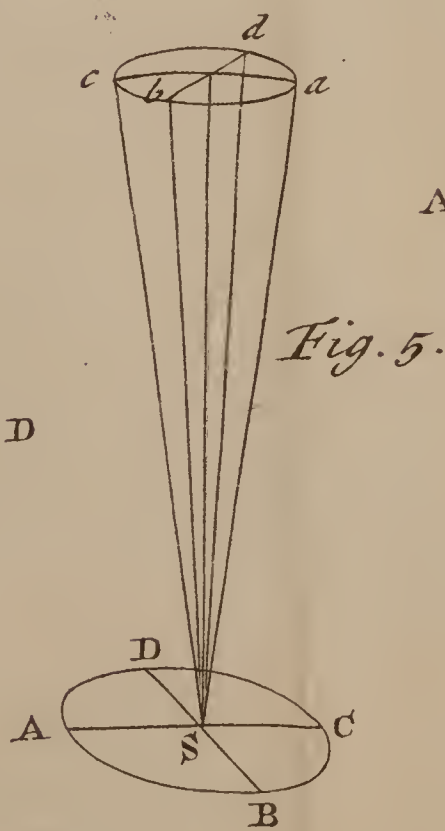
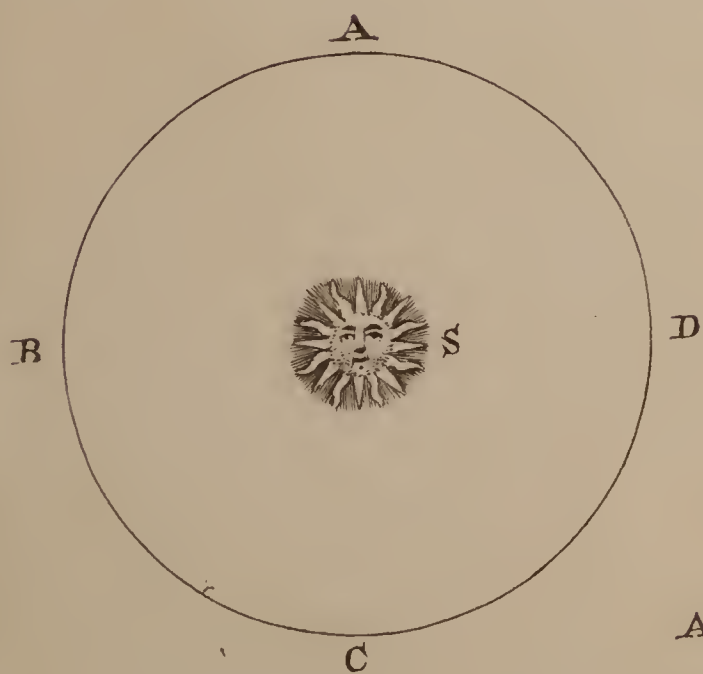


Fig. 5.

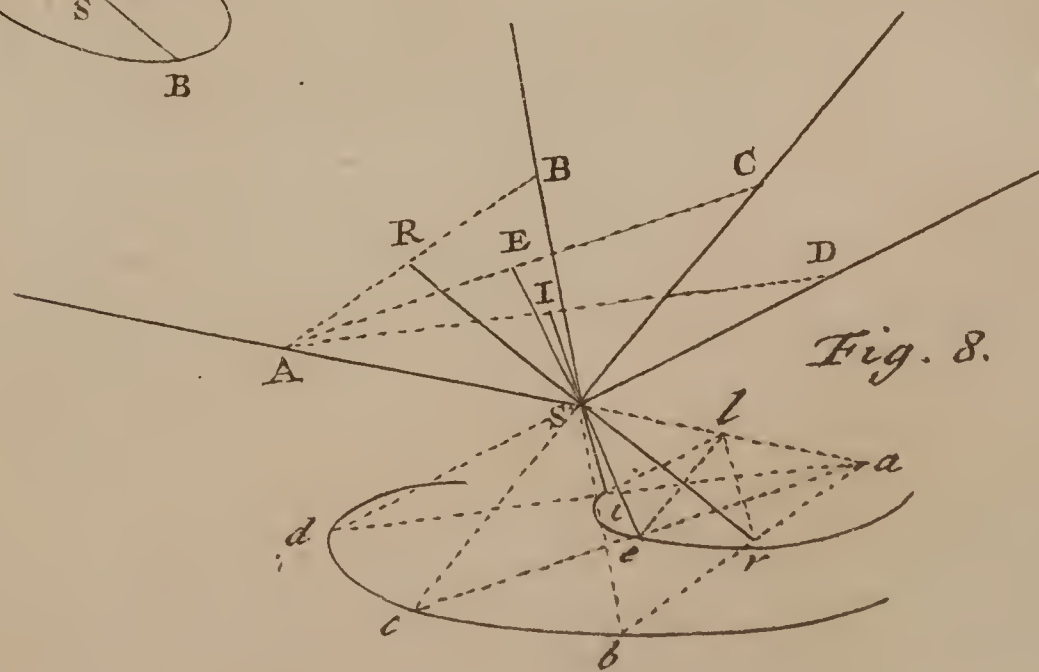


Fig. 8.

rection of the Rays be le parallel to CS ; if they be directed along DS and li , the Tail must be directed along i . If this be every where observ'd, SA will always be the reflected Ray.

Hence it follows, that the Ray reflected along SA remains fix'd, when the Tail of the Speculum continually concurs in the Circumference of the Circle ier with the Sun's Ray that passes through l . But we shall demonstrate that the Machine, describ'd above, performs this. 2718.

The Index of the Clock moves with the Sun, and the middle Point of the Pipe R , describes a Circle parallel to the Equator, for the Pipe is suspended in such Manner, that the middle Point is not alter'd, by varying the Inclination of it, or turning the Piece T , that sustains the Pipe *. This * 2681.2682. is the Circle, that is mark'd with the Letters ier in this Figure. 2719.

The Index of the Clock is so order'd, that, during it's Motion, the Ray of the Sun, which passes through the Point l (Pl. 83.) which is the same with the Point l in this Figure of ours, may also always pass through the said middle Point of the small Pipe *, through which Point also the Axis * 2695.2669. of the Cylinder continually passes, which makes the Tail of the Clock; therefore the Machine will perform all, that is requir'd *, if the Center * 2697.2718. of the Speculum be well order'd.

In the Delineation of the Machine, and in the present Figure, the Point l is marked with the same Letter, and in this S represents the middle Point of the Surface of the Speculum, which Point remains unmov'd in the Agitation of the Speculum. Therefore we must demonstrate that l in this Figure is constituted with respect to S , as l is in that with respect to the Center of the Speculum. 2720.

In both Figures the two Points are in the reflected Ray continued *: * 2693.2697. The Distance Sl , in this last Figure, is equal to any Line as li , or le *; 2714. these Lines make an Angle with the Plane of the Circle ier equal to the Declination of the Sun, and these Lines, and therefore Sl , are equal to the Secant of this Angle, when a Circle is made use of, whose Ray is equal to the Semidiameter of the Circle ier ; this Semidiameter answers to the Length of the Index *, and the Ruler of the Placer is divided in * 2680.2619. such Manner †, that the Length of the Part, which measures the Distance between the Center of the Speculum and l *, is always equal, according to the Time given, to the Secant of the Declination of the Sun, at that Time, the Ray of the Circle being given equal to the Length of the Index; to this Secant is also equal the Distance between l and the middle Point of the small Tube which follows from the Direction of the Sun's Rays *. Therefore every Thing answers in the Figures, which remain'd to be demonstrated. * 2690.2691. * 2688. 2695.

When the Sun is in the Equator the Point l coincides with the Center of the Circle ier . When it is in the Southern Signs, l is depress'd below the Plane of the Circle ier ; for this Reason the Legs of the Piece T are pretty long, that we may in the Winter raise the Pipe, through which the Tail of the Speculum passes. 2721.

C H A P. III.

Of the Inflection of the Rays of Light.

2722. **W**E have shewn before that Fire is attracted by Bodies * ;
 * 2398. this appears plainly in the Sun's Rays, which are bent to-
 2723. wards Bodies, when they pass along at a small Distance from the
 * 73. Bodies. This shews that *the Rays are* driven towards Bodies, and
 2724. *attracted by Bodies ** with some Force.
 * 75. The said *Attraction* is subject to the same Laws as that, which
 obtains between the small constituent Particles of Bodies *. *In Con-*
 * 2397. *tact it is very great* ; in this Case the Light joins itself to the Par-
 ticles of Bodies, as has been observ'd in general with regard to
 * 2421. Fire *, which appears directly from daily Observations made on
 Light ; for Bodies, which are illuminated with the Sun's Rays, do
 not reflect, or transmit them all, but many are extinguish'd in the
 Bodies themselves, and communicate Heat to them *.
 2725. The *Attraction* of which we are speaking, *suddenly decreases* as
 we recede from the Body, *and extends itself to a small Distance*,
 2726. which is yet *not altogether insensible* ; *at a greater Distance it is*
chang'd into a repellent Force, whereby the Rays are bent, and recede
from Bodies ; which Action, as you recede from a Body, is also di-
minish'd.
 2727. According to this Law the Rays are differently bent, as they
 Plate 86. pass at a small Distance from the Angle, which the Surfaces of a
 Fig. 1. Body make. Let C be an Edge, which such an Angle makes,
 which we suppose Acute, that the Effect may be the more sensi-
 ble. A Ray of Light consisting of many Rays parallel to one ano-
 ther, when it passes near the Edge, is dispers'd ; that Ray of those,
 into which the first Ray is divided, which passes at the least Di-
 stance, is attracted the most strongly ; A B is bent towards F.
 As we recede from C, the Deflection is diminish'd, and the Ray
 H I passes on in a strait Line. If the Distance is increas'd there is
 a Repulsion, which suddenly increases, and again decreases ; for,
 when the Repulsion obtains, we find that it is greater at a less than
 at a greater Distance, a Ray, as D E, is bent towards G.
 Among the Experiments, which belong to this Matter, I shall
 select those, from which the said Properties of Light manifestly
 follow.

A M A C H I N E,

Whereby Experiments concerning the Attraction, and Repulsion, of Light, are made.

The Plate A B E is of Brass; to this are applied the Rulers B F, 2728.
E G, made of the same Metal, between which the Steel Plate I is Pl.86.F.2.
moveable, which is thrust forwards, and drawn backwards, by
Means of the Screw C; a like Steel Plate H is applied to the
Plate A B E, and fasten'd by Means of the small Screws *n*, *o*.
These Plates cover a square Aperture in the Plate A B E; the 2729.
Sides of this Square are equal to half an Inch. The Surfaces of
the Plates I and H, which touch the Plate, are plane; and the
Plates are so cut, that each has an Edge *a b*, which are more or
less separated, or join'd together, by turning the Screw C.

The Hole, through which the Screw *n* goes, is somewhat wider, 2730.
that the Plate H may turn a little about the Center *o*, and that it's
Edge may be inclin'd a little to the other; in this Position it is fix'd
by the Screw *n*, and both the Edges can come together only in
one Point.

The Plate H is sometimes applied to the opposite Surface of the 2731.
Plate A B E, whose Thickness is equal to about a twelfth of an
Inch; it is fastened by Means of the Screws *n*, *o*, which go in-
to the same Holes of the Plate A B E. The Position of the Plate
H is inverted, that the same Surface of it may touch the Brass
Plate.

In the Representation of the Machine the Dimensions are reduc'd
to an half.

To the Board T, which is here reduc'd to a sixth Part of it's 2732.
Dimension, we apply the Plate mention'd *, and fasten it by Means Pl.86.F.3.
of Screws. We represent the opposite Surface of the Board, that * 2728.
the Aperture L may appear, which is an Inch high, and a little
broader, which the Plate itself covers: The Board stands upon
Feet that it may keep it's vertical Position.

In the following Experiments we make use of the Heliostate *, 2733.
which is the most convenient; but as all, who may be willing to * 2660.
make these Experiments again, and consider their Circumstances,
cannot make use of such a Machine, either by Reason of the want
of Skill in the Workmen that make them, or for some other
Reason, I will also shew how these Experiments may be made
without the Heliostate. And I shall observe this Method, viz.
When

When any Thing peculiar is to be observ'd in an Experiment, made without the Helioſtate, I ſhall make mention of it.

EXPERIMENT I.

2734. We have Occaſion for an horizontal Ray in this, and the following Experiment; according to what is explain'd in the laſt Chapter, we fix the Helioſtate in ſuch Manner, that ſuch a Ray may paſs through that Hole of the Plate, in the Side of the Box *, which may be narrow'd moſt.
- * 2705. If we wou'd make the Experiment without that Apparatus, and 2735. remove only the firſt of the Inconveniencies mention'd *, we Pl. 89. F. 4. ought to fix in the Window, when ſhut, a Plate, like that mention'd †, that the Light may enter in through a Hole, whoſe Magnitude may be alter'd, as before. We make uſe of a Hole in this Experiment, whoſe Diameter is about a Quarter of an Inch. We reflect the Ray with a plane, metallic Speculum; the Speculum is ſuſtain'd by a Tripod, like that, which is uſ'd in meaſuring of Land, and on which is put a Cylinder, which has a Ball that moves in it, whereby the Speculum may be turn'd any Way. We ſo diſpoſe this, that the reflected Ray may be horizontal.
2736. This Ray is directed ſo that it may paſs through the Aperture L of the Board F *, which is plac'd at the Diſtance of fix or ſeven * 2732. Inches from the Window, and through the Aperture in the Copper Plate, join'd to the Board, ſo that it may fall on the Steel Plate applied to this Copper Plate *.
- * 2728. The Edges of the Plates † are plac'd parallel to one another, and † 2729. between theſe there is left a Diſtance of about a tenth of an Inch. The Light paſſes between the Edges, and falls upon white Paper, plac'd at the Diſtance of about three Foot from the Board T; the Rays, which paſs at the Mid-way between the Edges, make a white Spot, on both Sides of which the Light extends itſelf like the Tail of a Comet; which clearly demonſtrates the Inflection of the Rays, ariſing from the Attraction as they paſs along near the Edges.
- The Diſtances, which have been mention'd, of the Board T, and the Paper, may be varied.
2737. In this Experiment the Repulſion of Light does not appear; becauſe the Light that is repelled, is mix'd with that, which paſſes on directly; but this is made manifeſt by the following Experiment.

EXPERIMENT 2.

Things remaining, as in the foregoing Experiment, the Edges must be gently mov'd towards one another, by turning the Screw *; * 2738. 2728. then the white Space is narrow'd, and on each Side of it there appear three colour'd Borders, parallel to the Edges; of the Colours I shall speak in the last Part of this Book. The Edges being brought still nearer to one another, the white Space is dilated more and more, and the Borders made on both Sides by the attracted Light, are remov'd on both Sides, and the intermediate Space is at length so darken'd, that it is manifest, that none of the Light passes on in a right Line.

These Phenomena appear more distinctly, when the Aperture in the Window is narrow'd. 2739.

Whilst the Edges are mov'd towards one another, the Rays, which are attracted by one Edge, fall into the Sphere of Repulsion of the other Edge, and are repelled; by that the first Inflection is increas'd, and the Lights are remov'd farther on both Sides, and the middle Space is increas'd. Therefore the Experiment demonstrates the Repulsion; and it also appears that it is greater at a less Distance *. 2740. * 2726.

EXPERIMENT 3.

We also immediately demonstrate, that in these Cases the Actions of both Edges concur upon the same Rays; for if one Edge be put into a tremulous Motion, the other being at Rest, the Light, bent on both Sides, is affected with a tremulous Motion. 2741.

We said that the Distance, at which Light acts upon Bodies, is not altogether insensible *; this also appears in the second Experiment; for if the Distance between the Edges be equal to a fortieth Part of an Inch, none of the Light passes on in a strait Line, but it is all turn'd aside. 2742. * 2725.

From the second Experiment we also infer, that the repellent Force diminishes, as the Distance increases; this we have also affirm'd of Attraction *; which also is deduc'd from Experiment. 2743. * 2725.

EXPERIMENT 4.

When the Distance between the Edges is so diminish'd in the second Experiment, that no Light passes between them in a strait Line, if the Distance be still diminish'd, the Borders disappear successively, 'till the Edges being join'd, no Light passes between them. 2744.

2745. It is manifest that those disappear first, which are made by the Rays, more remote from the Edges, and that those disappear last, that are made by the Rays that pass along the nearest to the Edges. But the inward Borders, which are made by the Rays less bent, disappear first, and the outward ones last; which shews, that those Rays are the most bent, which pass along at the least Distance from the Edges.

EXPERIMENT 5.

2746. The principal Phenomena, observ'd in the foregoing Experiment, may be seen at one View only, if the Plate H be a little inclin'd, in such Manner, that the Edges may make a small Angle *, and be contiguous at one End. Then as the Rays pass between the Edges, we see at the same Time, what obtains at different Distances; this is represented at Fig. 5.

Pl.86.F.2. * 2730. The Phenomena, hitherto explain'd, differ but in one Circumstance from those, which we observe, when the Steel Plates are so dispos'd, that the Rays may not come to one Edge, without passing over the other.

2748. Let H be one Plate; I the other, more remote from the Hole, through which the Light enters; the Phenomena are easily discover'd.

* 2723. The Rays which pass near H, are attracted *, and repell'd †; the first are sensible, because they are bent towards the Shadow; † 2726. the others are mix'd with them, which do not pass directly beyond the Sphere of Repulsion. The same Thing obtains with respect to the Rays, that pass near the other Edge, and we observe the same Things, as were mention'd in the first Experiment *.

* 2736, 2749. If the Space, between the Edges, through which the Light passes, be so narrow'd, that there may be passage only for those Rays, upon which the first Edge, namely that of the Plate H, acts, those Things happen, which were explain'd in the second Experiment *; both Edges act upon all the Rays, they are repell'd by one, which are attracted by the other, which also immediately appears, if the third Experiment * be repeated in these Circumstances.

2750. In the fourth Experiment * we perceive this only Difference, all the Borders at the Part of the hind Plate I disappear, those remaining, which are painted at the other Part.

* 2744. 2751. When the Space, through which the Light can pass, is very narrow, the Light, reflected from the Edge H, as also all that which

Chap. 3. *of Natural Philosophy.*

I 2 I

which passes in a right Line, runs against the Plate I, and is intercepted; but that, which is attracted by H, and is therefore bent, passes through the Sphere of Repulsion of the Edge I; then no Light is bent towards I. If any of this bent Light falls into the Sphere of Attraction of the last Plate, the Effect cannot be sensible.

EXPERIMENT 6.

We remove the Plate R from its Place, and apply it to the opposite Surface of the Plate A B E *. We fasten that Plate in such Manner, that the Edges may not be parallel; but that one may be a little inclin'd with respect to the other, as in the fifth Experiment *; and we place them so that all the Light may be intercepted at one End. 2752. Pl.86.F.2. * 2731. * 2746.

All Things being now order'd as in the foregoing Experiments, the Phenomena arising from the different Breadth of the Space, through which the Light passes, are perceiv'd at one View, as in the fifth Experiment; the Figure, in which is represented what is here observ'd, only differs from the Figure of the said fifth Experiment with respect to the Rays disappearing at one Part, before those are intercepted, which are bent at the opposite Part *. Pl.86.F.7. * 2550.

We freely acknowledge, that the Causes of the Attraction and Repulsion of Light are conceal'd from us; but the Experiments, explain'd in this Chapter, fully evince, that they do really obtain; more might be added, which does not indeed so directly prove Attraction and Repulsion, but so manifestly flows from them, that, if there was Occasion, what has been hitherto explain'd, might be confirm'd by other Arguments. 2753.

B O O K V.

PART II. Of the Refraction of Light.

C H A P. IV.

Of the Machines, whereby the Experiments concerning the Refraction of Light are made.

2754. SEVERAL Machines, of which many are small, are made use of, in the Experiments, which belong to this second Part of this Book; but as I often use the same Machines, I thought it best, to explain them first, that the Series of the Explanation may not be too often interrupted.

A B O X,

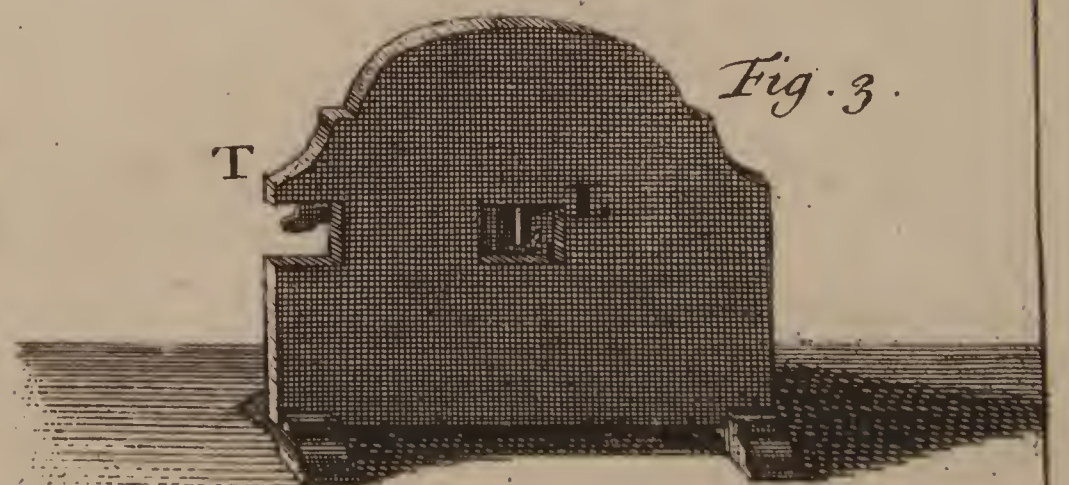
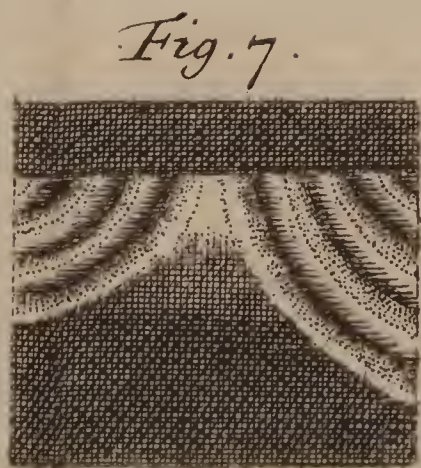
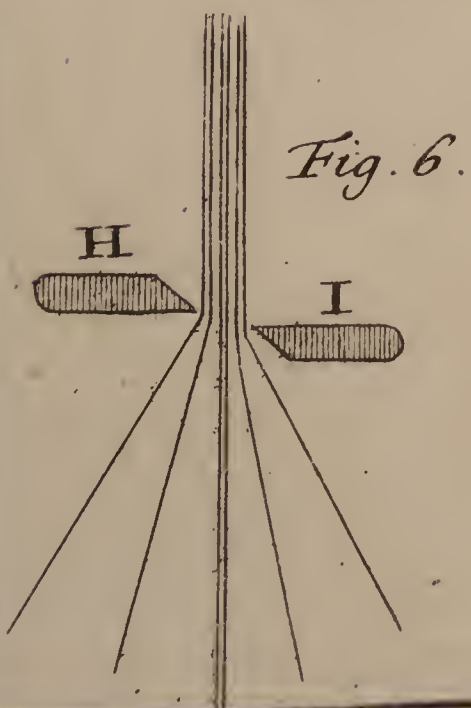
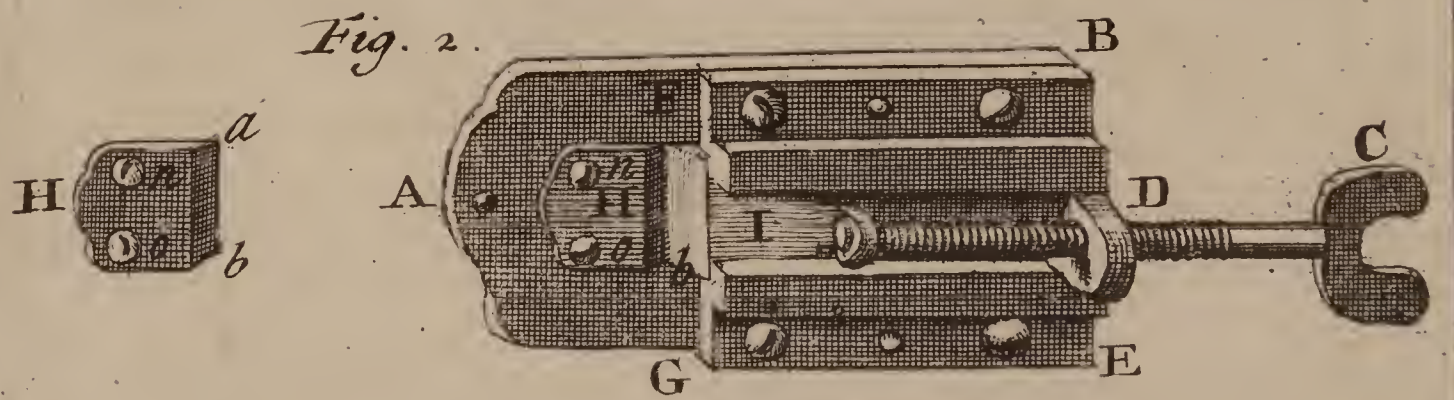
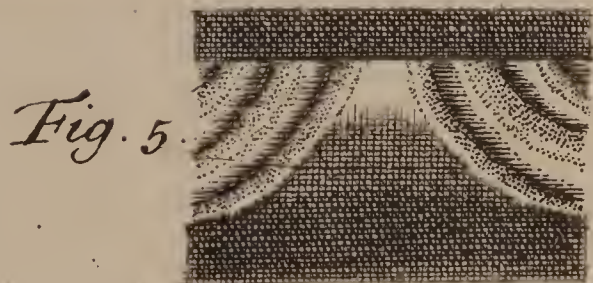
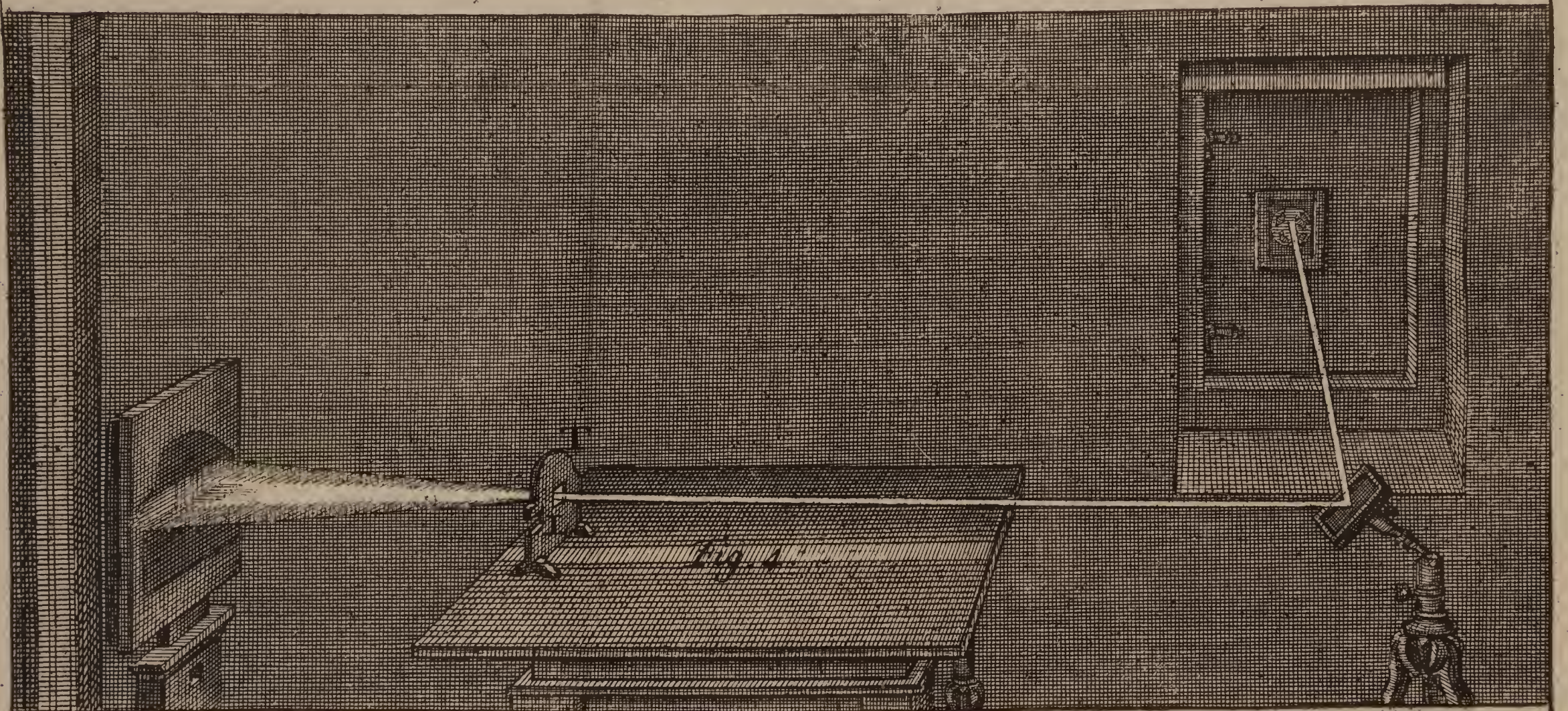
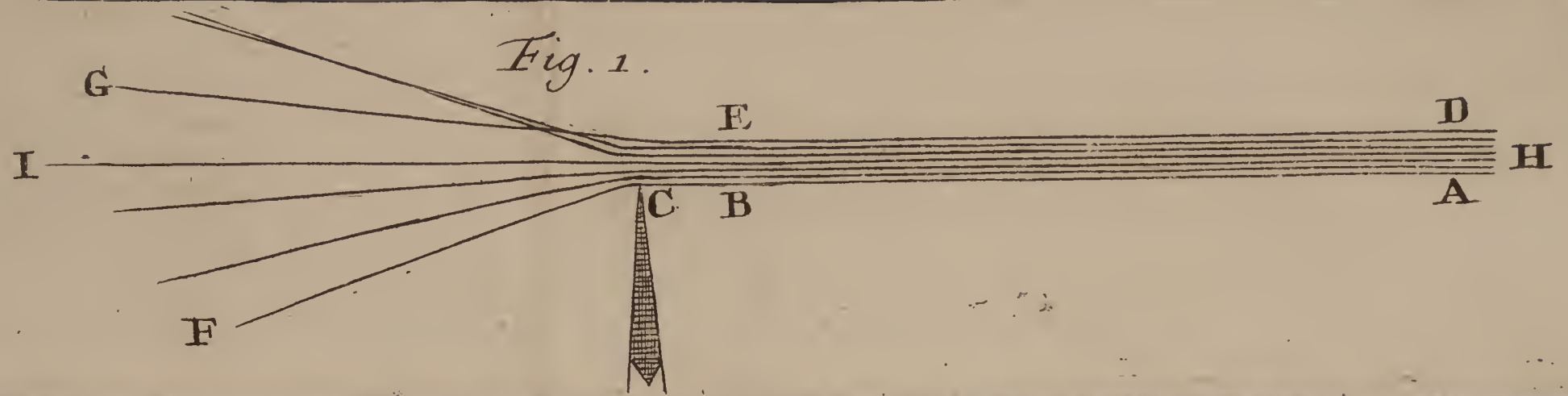
In which others are inclos'd.

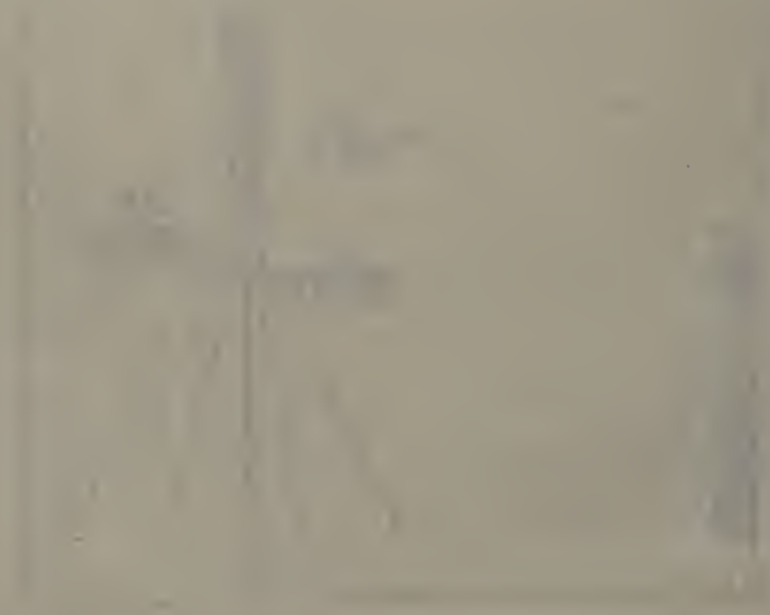
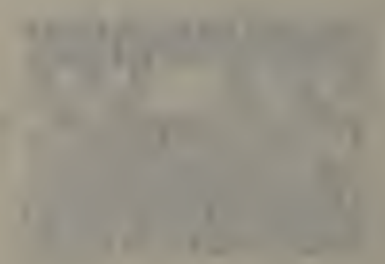
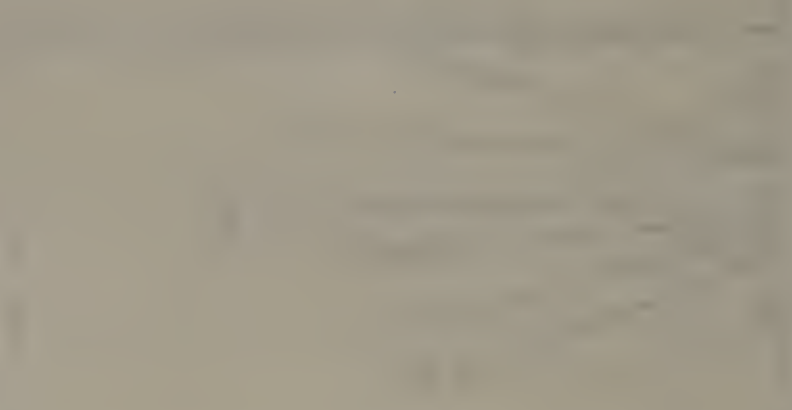
2755. This Box AB is about two Foot and an half long, and five Pl.87.F.1. Inches broad and deep. The Sides have Openings, the middle Part being taken away, and the extreme Parts only remaining, as C, D. The middle Part, which is taken away, is supplied by two Boards on each Side; as EF, at the fore Part of this Figure; H, G, behind. These Boards are moveable in Grooves as *ab*; F is represented in such a Position, that if they were all thus, the Box is open'd laterally, as much as it can be.

2756. The Board G is represented drawn out of it's Place; if H shou'd be drawn out in the same Manner, this wou'd meet G; thus also E and F may meet.

2757. The Box is open at Top, as also at the End B; one End is clos'd, the Hole *d* being left in the Middle, whose Diameter is an Inch and a Quarter.

BOXES,





B O X E S,
Terminated by Glafs Planes.

The Box M L I has a wooden Bottom ; the End I is also clos'd ^{2758.}
by a wooden Plate ; the other three Sides are of Glafs ; but the Pl.87.F.2.
Pillars L and M are of Wood. The Glafs Plates are plane and
smooth, and like those of which looking Glaffes are made ; these
go into Grooves in the Wood, and are fasten'd, that the Box may
hold Water.

We have another Box of a somewhat different Construction, and
I prefer this second Method ; I only made mention of the first ;
because the Box is more easily made, when the Glaffes are put into
Wood.

The Bottom of the Box P is made of a Brass Plate R S, whose ^{2759.}
Ends being bent make Feet, whereby the Box is rais'd about one Pl.87.F.3.
Inch.

To this Plate are join'd, and stand perpendicularly upon it, the
four Brass Rulers, *ab*, *bc*, *cd*, *da*, whose Ends are join'd at
a, *b*, *c*, *d*. The four Sides of the Box are of Glafs, made of
Plates, like those above-mention'd. These Plates are applied to a
Copper Bottom in such Manner, that they are surrounded by the
Brass Rulers, a small Interstice being left ; the Extremities of the
Plates come together, but so that the smaller Plates may be plac'd
between the greater ones.

The Glafs Plates are join'd to the Bottom, and the Rulers, and ^{2760.}
together, by putting between them a Mixture of Rosin, and white
Wax, in a small Quantity.

B O X E S,
That have spherical Glaffes.

The Box P is of Wood, nine or ten Inches long, and three broad ^{2761.}
in the Inside. At the Ends of it there are Holes, one of which Pl.88.F.1.
appears at V ; these are clos'd with thin Glaffes, making Portions
of Spheres, which are put into the Wood, and fasten'd with Ce-
ment. We make use of such Glaffes as are us'd in Watches ;
those are to be made choice of which are every where of the same
Thickness, and are thin. These Glaffes are so plac'd, that the
Convexity of the one may stand out beyond the Box, and that of
the other may be turn'd towards the Inside of the Box. It is also
to be observ'd, that the Diameter of the Holes, to which the

Glasses are applied are equal to an Inch and a Quarter ; but that the Diameters of the Glasses ought to exceed them half an Inch.

A Section of the Box along the Length is represented at p , the Glasses appear at v , v .

2762. The Boards T, S, are sometimes put into the Box ; they go across it, and are sustain'd by Means of the Prominences a , b , and a , b , and reach almost to the Bottom : But that they may keep their vertical Situation, when Water is pour'd into the Box, Lead is put into the Wood at $c d$, $c d$.

2763. In the Board S is fasten'd the Glass Q, convex on both Sides, which collects the Sun's Rays at the Distance of an Inch.

2764. The Board T is made white ; but S must be made black, as also all the Boxes, and most other Instruments, which are us'd in Experiments concerning Light.

2765. To the Box P is join'd another A D B, open at A in such Manner, that either End of the Box P may be put into this End. One End of the Box A B, namely D, is clos'd, and has a Hole in the Middle of it : The Hole is equal to the Holes in the Box P, and answers to them in such Manner, that when the Boxes are join'd together, Light may be transmitted through the three Holes.

2766. A third smaller Box is represented at E F ; in one of it's long Sides there are two Holes V, R, equal and similar to those, which are in the Box P, and clos'd in the same Manner with Glasses * ;
Pl.88.F.3. * 2761. the Convexity of the Glass at V is on the Outside, at R it is on the Inside. In the opposite Side G there is put a plane Glass Plate, that the Light may come directly to V and R.

The transverse Sections of this Box, along the Centers of the Glasses R and V, are represented at H and I ; the Glasses appear at r , v .

A G L A S S C U B E.

2767. The Cube C is made of pure Glass ; this must be nicely work'd, Pl.87.F.4. so that the Figure may be accurately cubical. It's Surfaces must be plain, smooth, and well polish'd. The Sides are equal to two Inches.

In the Experiments this Cube, that it may not be damag'd, is put upon a Piece of black Cloth. It is convenient to make use of a Board as T, cover'd with such a Cloth.

B O A R D S,

Through which Light is transmitted.

We make use of various vertical Boards, for this Purpose. In the first, whose fore Part and hind Part is represented, there is a vertical Incision *ab*, which is a Quarter of an Inch broad. This is clos'd at the fore Part of the Board, with a Plate of Wood A, which is dove-tail'd, and moves between two Rulers. By this Method the Aperture is terminated, wheresoever you please, toward this upper Part. 2768.
Pl.87.F.5.

Behind the Table there is applied to it a Board B, which is also dove-tail'd, and moves between two horizontal Rulers. By Help of this the Aperture is terminated as you please towards the Bottom. The two Pieces of Wood are made use of both together, that the Aperture may be rais'd, depress'd, and extended at Pleasure.

There is a second Board that differs little from the first; it's Incision is horizontal half an Inch broad, which is diminish'd at Pleasure, by one dove-tail'd Plate only, which moves between Rulers. It is sufficient to diminish the Aperture towards one Way, because the Board itself may be mov'd horizontally. 2769.
Pl.87.F.6.

We have Occasion for a third Board T like the other; the Aperture of this is greater, being an Inch and a Quarter broad, and is terminated by a Semicircle both Ways; above this there moves between two Rulers another Board H, which has a Hole in the Middle of A. To the Hole, whose Diameter shou'd be equal to an Inch and a Quarter, is applied and put into the Wood a convex Glass, which collects the Rays of the Sun at the Distance of about eight Inches. 2770.
Pl.87.F.7.

The Glass U answers to the Aperture, and may be rais'd, or depress'd, the Space of one Inch, without intercepting the Rays transmitted through the Glass. 2771.

We also make use of a smaller Board T which is furnish'd with a like Glass. A Section of this Board is represented at *t* when this is put into one or other of the Boxes mention'd in N. 2755, or 2765, the Light, which is admitted through the Hole at the End of the Box, is transmitted through the Glass, which is to be so ordered, that the Center of it may answer to the Center of the Hole. 2772.
Pl.88.F.4.

AN HORIZONTAL BOARD.

2773. Oftentimes Instruments, and other Things are to be rais'd upon
Pl.88.F.5. a Table to a determined Height which is different according to different Circumstances. For this Purpose we make use of a Board T, whose Foot is represented at P. The Pillars C, C, which pass through the Holes *a*, *b*, of the Board T, which is then horizontally sustain'd by the round outward Screws E, E, which are placed at the required Height. The Board is fasten'd by applying to it the like outward Screws D, D.

All the Figures of the Machines explain'd in this Chapter, I reduce to a sixth Part of the true Magnitude.

T A B L E S,

Whose Height may be alter'd.

2774. We make use of several Tables of this Kind; I make use of three; the length of one is two Foot and an half, and it's breadth two Foot.

There are two other smaller ones fifteen Inches long, and a Foot broad.

The Construction of them is commonly known; to each there is firmly join'd a square wooden Pillar, almost two Inches broad and thick, which supports the Table. This Pillar is moveable in a Sheath, which is made of four thin Pieces of Wood. This is sustain'd in a vertical Position, at the Height of about eight Inches from the ground, three Feet being fasten'd to it's lower End, which spread at Bottom.

The Table is rais'd at Pleasure, by drawing the Pillar out of the Sheath, more or less; it is fasten'd by Means of an Iron Screw which passes through a Ring of the same Metal, which surrounds the upper Part of the Sheath. That the Wood may receive no Damage a Copper Plate is put between in such Manner, that the Screw presses one End of it, whilst the other End coheres with the inward Surface of the Sheath, that the Plate may not fall out of it's Place. By a like Method or any other Method, a Rectangle made of wooden Rulers is rais'd at Pleasure, and fasten'd, to which is applied a Paper, upon which the Light falls, in many Experiments. Such a Rectangle is of use in the Experiments of the foregoing Chapter.

Fig. 1.

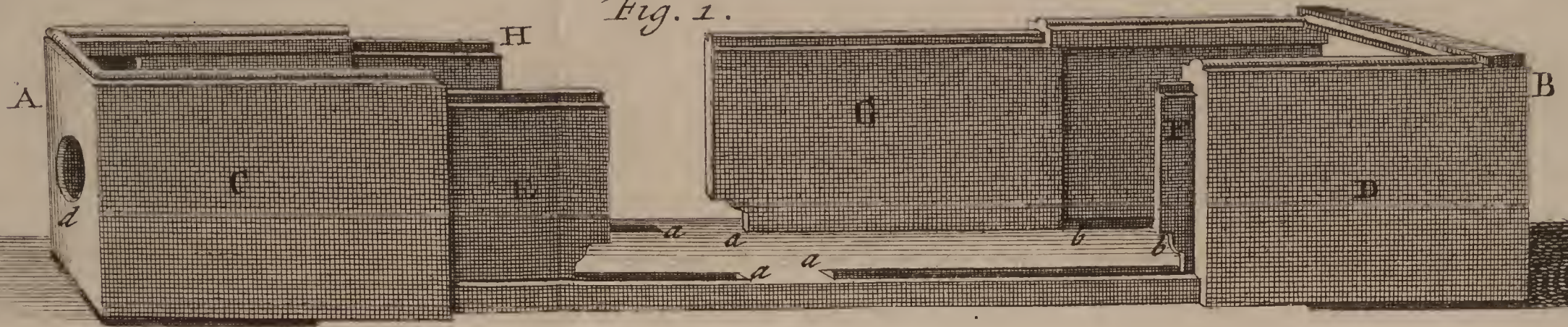


Fig. 2.

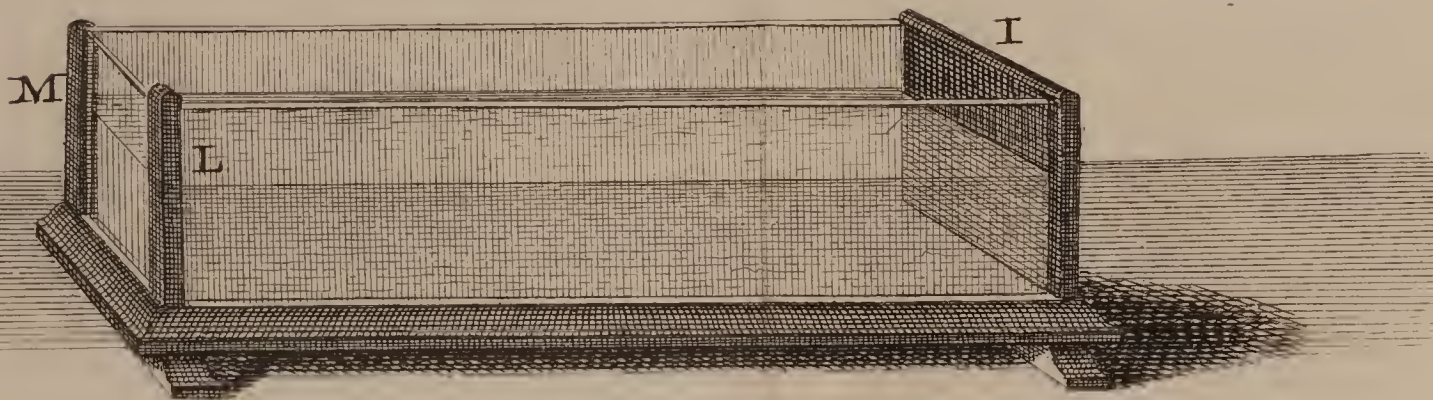


Fig. 4.

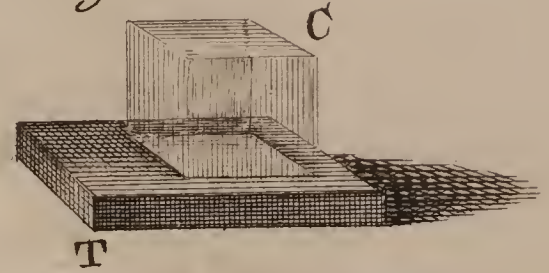


Fig. 3.

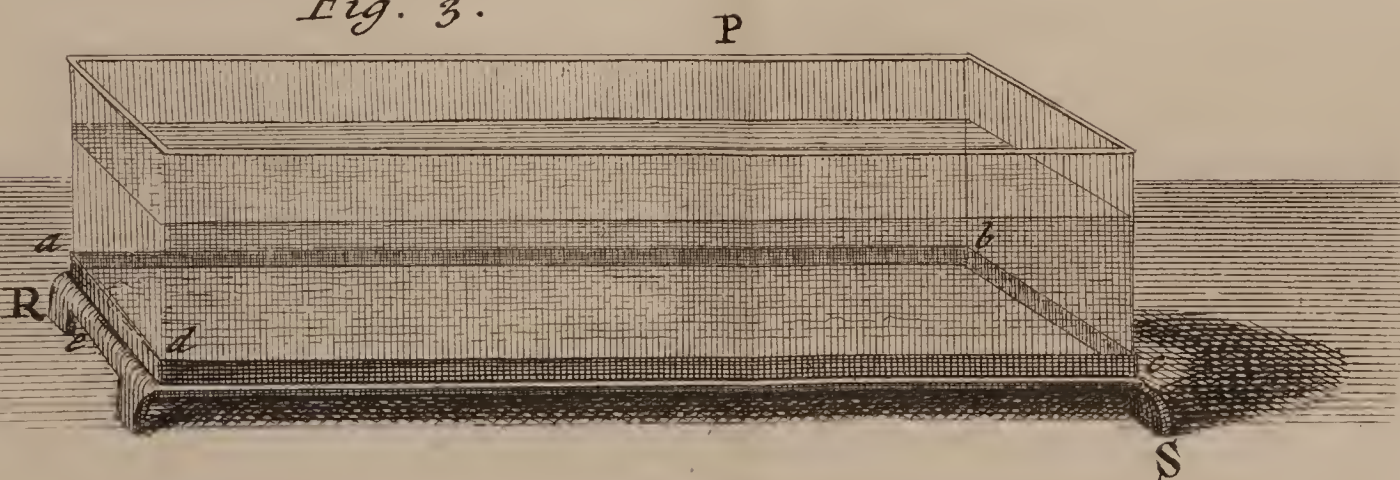


Fig. 7.

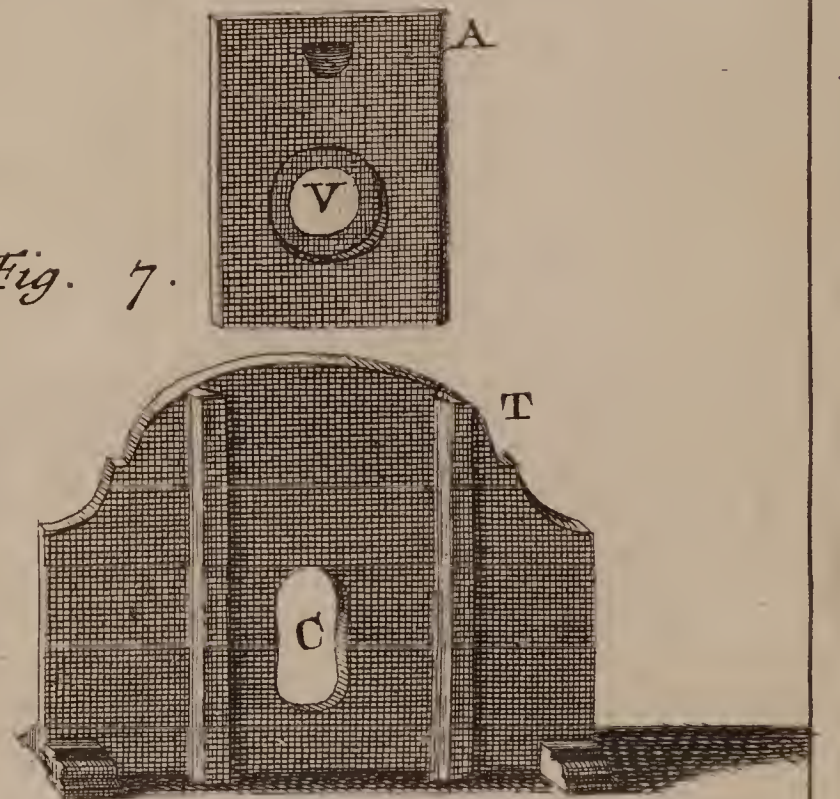


Fig. 6.

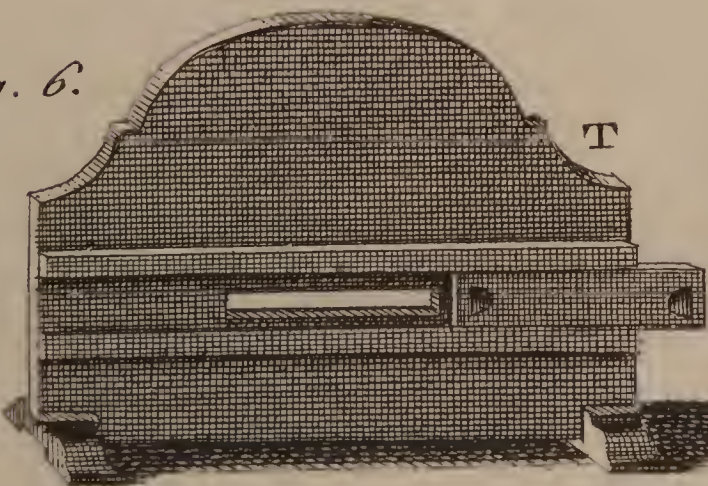
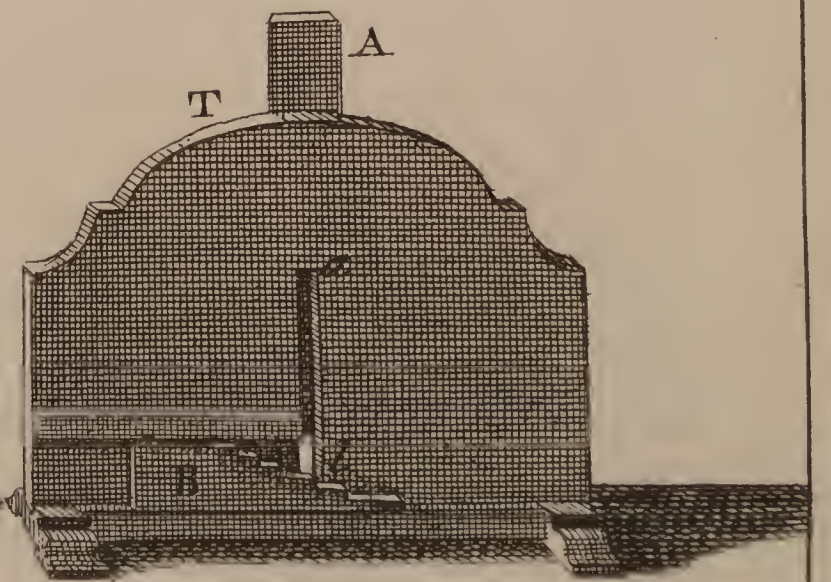
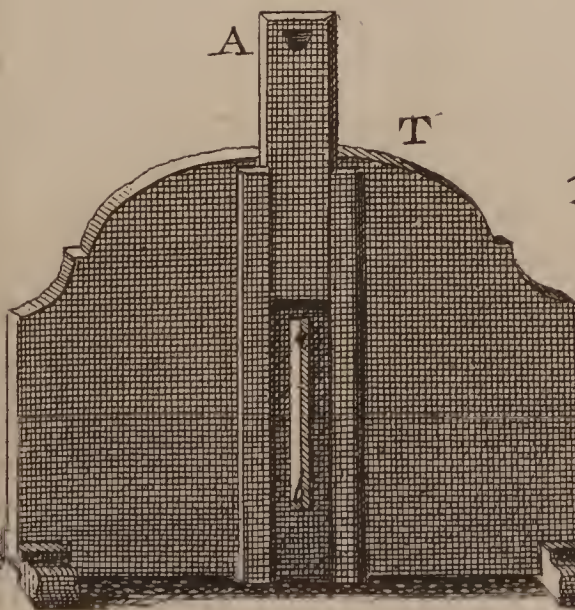
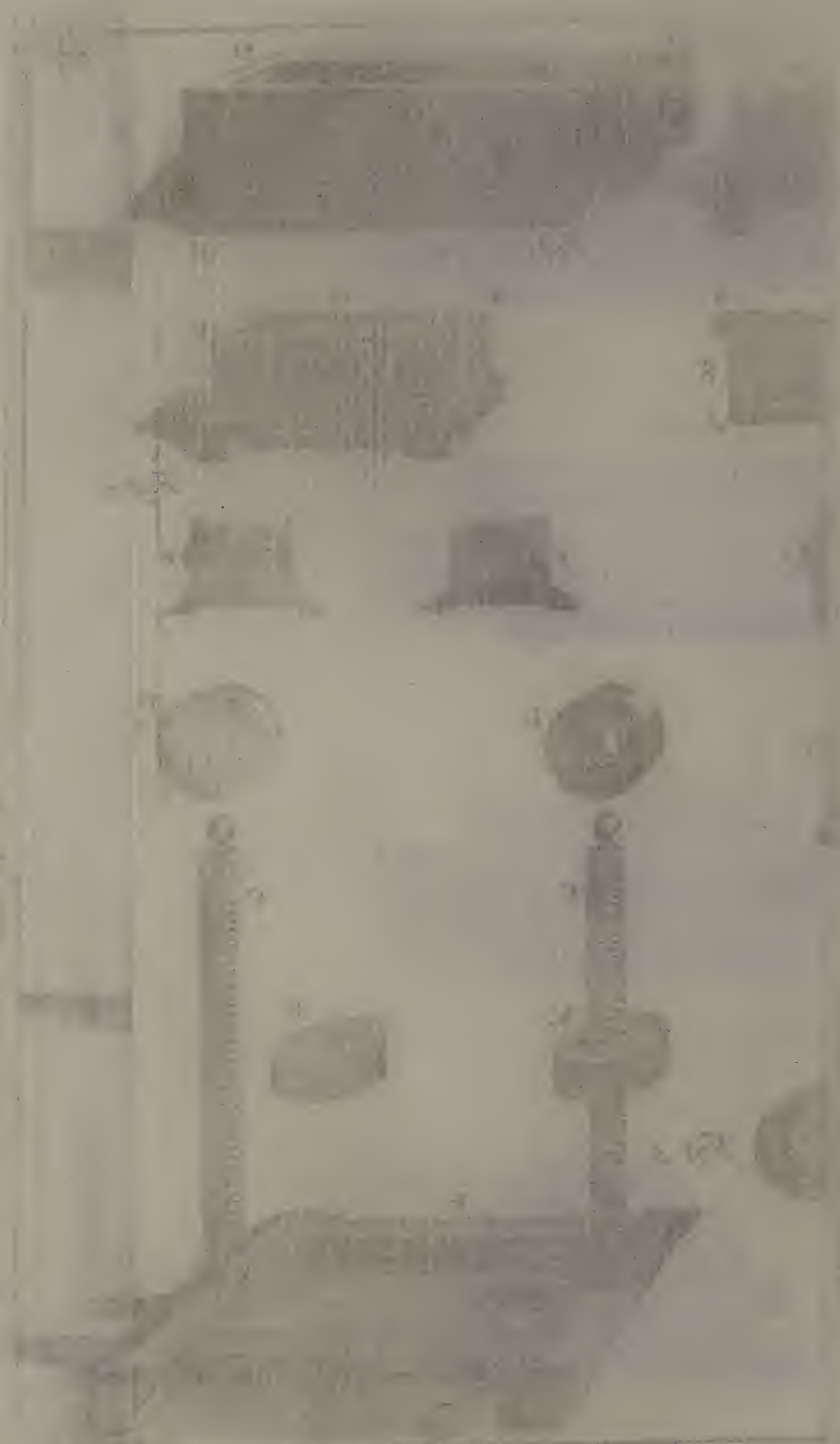


Fig. 5.





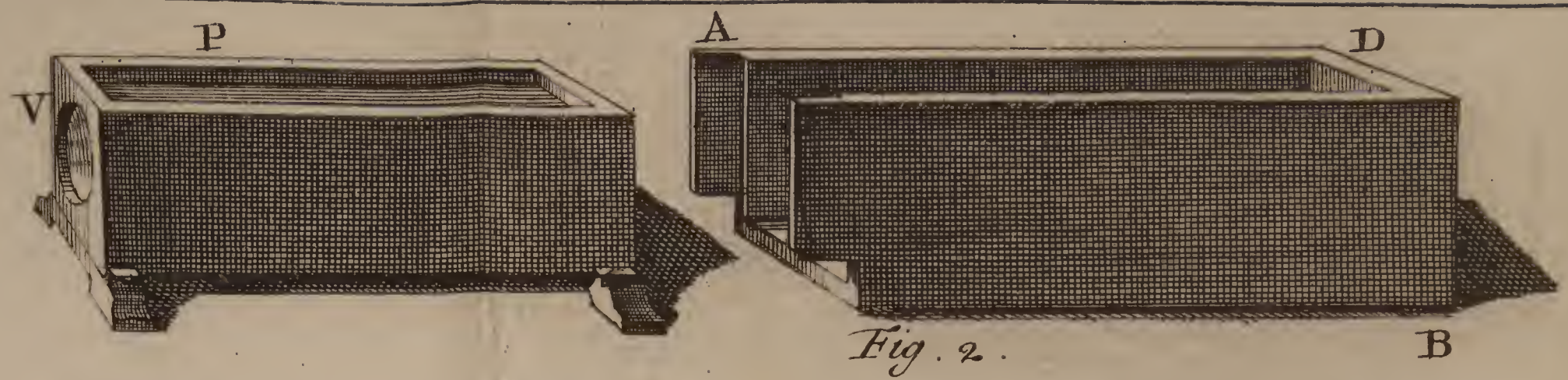


Fig. 2.

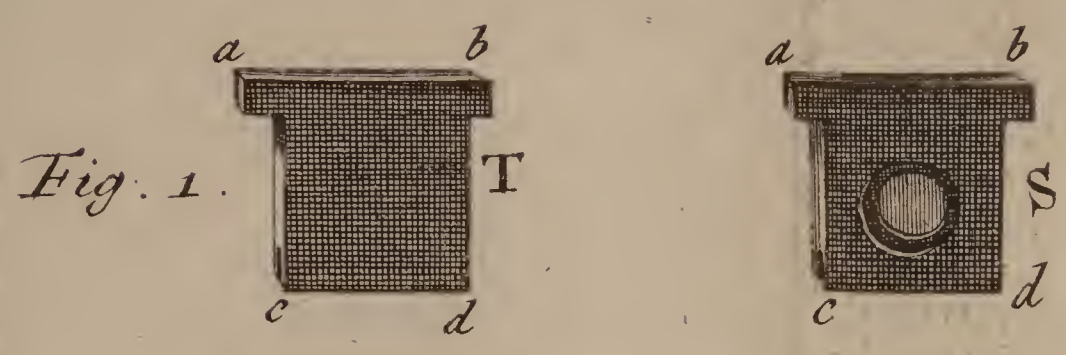


Fig. 1.

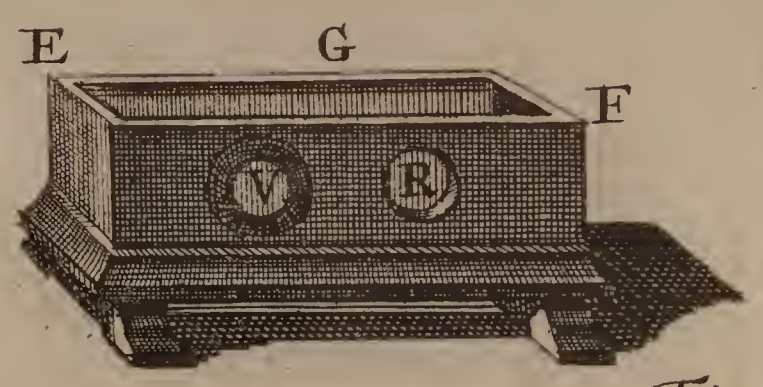


Fig. 3.

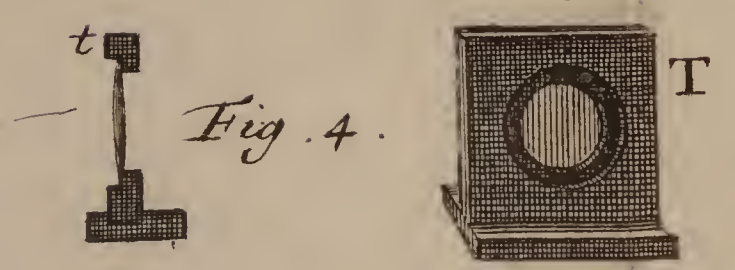
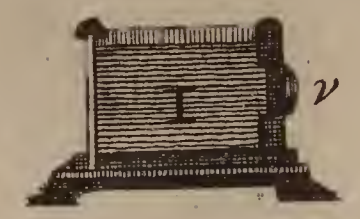
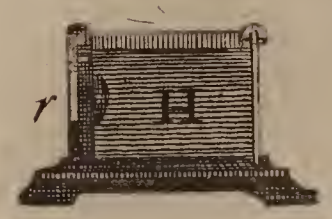
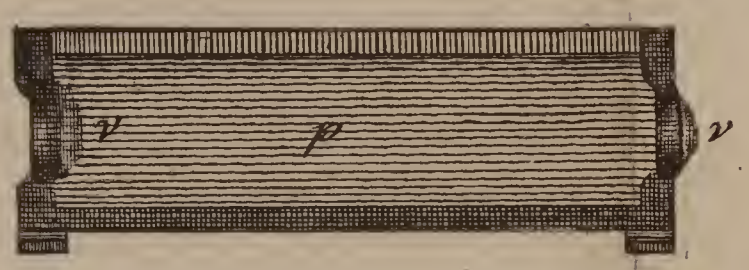


Fig. 4.

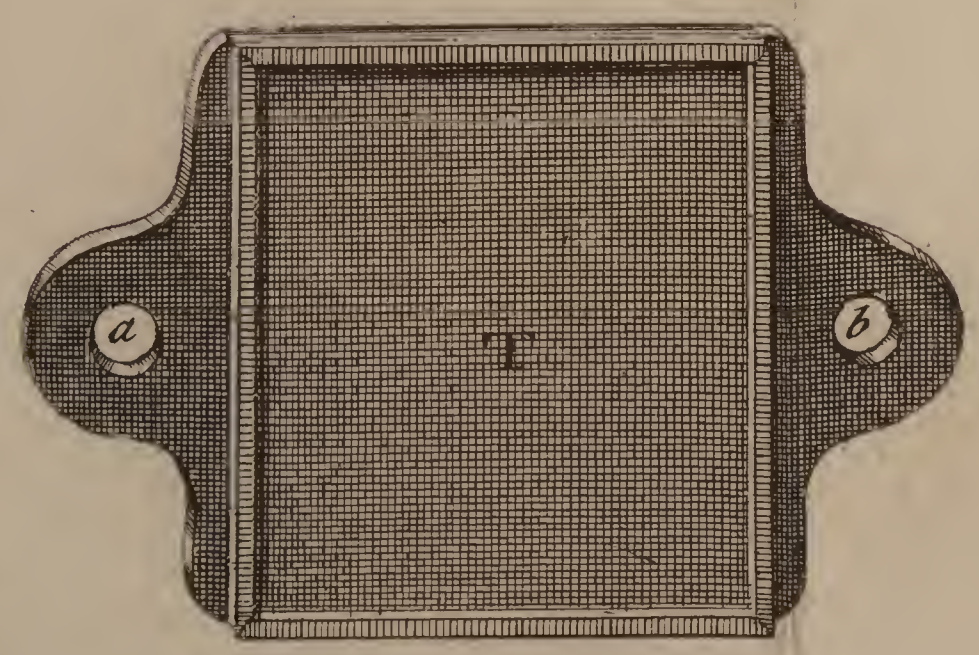
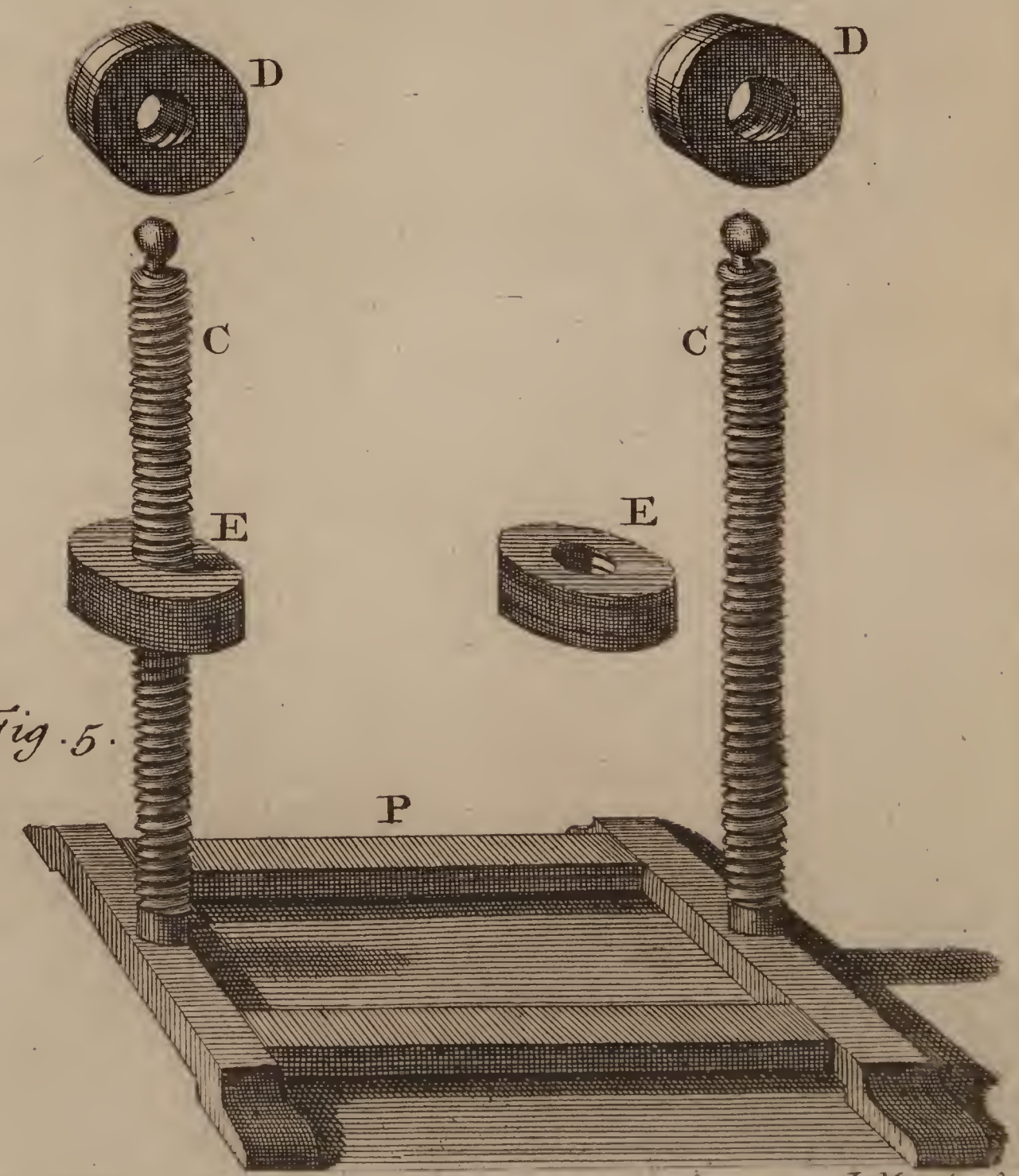


Fig. 5.



C H A P. V.

Of the Refraction of Light, and it's Laws.

DEFINITION 1.

EVERY thing that gives a Passage to Light is call'd a Medium. 2776.

All pellucid Bodies, * a Vacuum, are Mediums. * 2614.

Whilst a Ray of Light goes out of one Medium into another, it often turns out of it's Way.

DEFINITION 2.

This Inflection is call'd Refraction.

In order to produce Refraction, the Medium must be of different Densities, and the Ray make an oblique Angle with the Surface which separates the Mediums. 2777.
2778.

Refraction arises from this, that the Rays are more attracted by a dense than by a rare Medium; from which Attraction, all that we have proved in the foregoing Chapter, relating to Refraction, is deduc'd. 2779.

Let EF be the Separation of the Mediums; let the Medium be Pl. 89. F. I. denser, and rarer towards Z. All the Particles of Matter attract Light *. Let the Distance, at which Particles exert their Action, * 2723.
be that contained between the Lines EF, and GH. Therefore the 2780.
Light, which comes between these Lines, will be attracted by the denser Medium X; and indeed perpendicularly to the Surface, which separates the Mediums; for the oblique Actions on every Side are similar and equal, and jointly draw perpendicularly.

At the Distance of the Line GH, the extreme Particles of the Medium X do only act upon the Light; at a less Distance, both these and other Particles act so as to increase the attractive Force, when the Distance is diminish'd, as has been observ'd before *. * 2725.
In the denser Medium X, let the Line IL be at the same Distance from EF as GH is in the Medium Z. Let the Light enter into the Medium X, and it will every Way be attracted by the Particles of the Medium, whose Distances from the Light are less than the Distance between EF and GH; for at that Distance the Light is supposed to be attracted by the Particles of the Medium X.

As

As long as the Light is between the Lines EF and IG , the attractive Force is the strongest towards IL ; because there are more Particles that attract that Way: But as the Number of Particles, acting the contrary Way, does increase, that is, as the Distance from EF increases, the Force towards IL diminishes, till the Light be equally attracted every Way in that Line IL , which also is every where so in the Medium X beyond IL .

2782. Suppose a Ray of Light Aa to fall obliquely upon the Surface dividing the Mediums, or rather on the Surface GH , where the Action begins, by which the Light is driven towards the Medium X ; when the Ray comes to a , it is turned out of the right Line by the Force, wherewith it is driven towards it in a Direction perpendicular to it's Surface. And indeed the Ray of Light is bent out of the right Line in every Point, so long as it is between the Lines GH and IL , between which the said Attraction acts; and so the Ray describes the Curve ab between those Lines, after the same Way as has been said Projectiles do * the Action, bending the Ray, ceases beyond the Line IL ; therefore it goes on afterwards in a right Line bB , being the Tangent to the Curve in the Point b .

* 540. The Distance between the Lines GH and IL is but small:

2783. Therefore in Refraction we take no Notice of the bent Part of the Ray, which is consider'd as made up of two right Lines AC , CB , meeting in C , viz. In the Surface separating the Mediums.

Through C draw NCM perpendicular to the Surface EF .

DEFINITION 3.

2784. The Part AC of the said Ray, is call'd the incident Ray.
* 1161. The Angle ACN is the Angle of Incidence *.

DEFINITION 4.

2785. The Part CB of the Ray, is call'd the refracted Ray.

DEFINITION 5.

2786. The Angle BCM is call'd the Angle of Refraction.

2787. In this Case when Light goes out of a rarer into a denser Medium, the Angle of Refraction is less than the Angle of Incidence; for these Angles wou'd be equal, if the Ray AC should have continued on it's strait Way, along the Line CD . But the Ray CB comes nearer to the perpendicular CM ; and therefore the Refraction is said to be made towards the perpendicular.

On the contrary, *if the Ray goes out of a denser Medium into a rarer, it will recede from the Perpendicular* ; because the denser Medium attracts the Ray after the same Manner, whether it goes out of a rarer into a denser, or out of a denser into a rarer Medium. Therefore if BC be the Ray of Incidence, CA will be the refracted Ray, that is, *let the Ray come from either Side, and it will move in the same Line.* 2788. 2789.

Therefore *if there be two Rays, and one comes out of a denser into a rarer Medium, and the other out of a rarer into a denser ; and the Angle of Refraction of the one be equal to the Angle of Incidence of the other, the two Angles of Incidence and Refraction remaining will be equal to each other.* 2790.

Let X be a Medium terminated by the Parallel Surfaces EF, HL, by which Z is separated from the same Medium on both Sides ; we suppose X to be denser, it is no Matter if it be rarer. The Light enters along AC, is refracted along CB, and goes out along BG, NCM, PBO, being drawn perpendicular through C and B, the Angle MCB, CBO are equal * therefore, by Reason * 29.El.1. of Attraction on both Sides acting in the same Manner, the Angles ACN, PBG, are also equal, but the Angle MCB is the Angle of Refraction, and the Angle CBO is the Angle of Incidence in the second Refraction ; therefore the two other are equal. 2791. Pl.89.F.2.

From whence it follows, that *the Direction of the Ray is not changed, if it moves through a Medium terminated by two parallel Surfaces* : For as much as it is turned at it's Entrance towards one Side, so much exactly is it turned the other Way as it goes out of the said Medium. It is manifest that the Rays AC, BG, which are equally inclin'd to the Parallels MN, OP, are also parallel. 2792.

If a Ray falls perpendicularly upon the Surface separating two Mediums, it will not be turned out of a right Line by the Attraction of the denser Medium ; because in that Case it acts in the Direction of the Ray. 2793.

EXPERIMENT I.

We fasten the small Side-Board * to the Box, in which the Heliostate is inclos'd, in such Manner that it may not quite close the Aperture, to which it is applied † ; but it wants three Inches * towards the Bottom, where there is left open a square Hole, through which Light is to be reflected horizontally *. But in order to exclude the extraneous Light, we apply a square wooden Tube, about a Foot long, and the Light is directed through the Tube. 2794. Pl.89.F.3. 2703. 2707. 2698.

This Tube is laid upon a small Table, whose Height may be alter'd *.

* 2774. 2795. If the following Experiments are to be made without the Helioſtate, the Light is let into a Place which is otherwise clos'd through a ſquare Hole of three Inches in the Window, and re-
* 2735. flected horizontally *.

* 2796. We make uſe of the long Box CA deſcribed above *; which
* 2755. we ſo diſpoſe, that the Light may enter in through the open End, and follow the length of the Box. The Light in it's Ingreſs is in-
* 2768. tercepted by the Board T *, and only let through a Slit in it.

When the Box is open towards the Sides, we put through it the
* 2758. Box P, which is terminated by Glaſs Planes * in a tranſverſe Poſi-
2759. tion. Towards this are mov'd the ſide moveable Boards of the firſt, which is thus clos'd as much as poſſible.

Water is pour'd into the Box P to half it's Height, ſo that a Ray of Light paſſes partly through the Water, and partly above it. The Aperture of the Slit in the Board T muſt be ſo terminated, that the Light may not fall upon the Bottom of the Box P, nor paſs
* 2768. above the Box *.

2797. Theſe Things being thus order'd, and the Box being turned in ſuch a Manner, that a Ray may fall upon ab perpendicular to it's Surface; the Light will paſs through the Water in a right Line, as alſo through the upper Part of the Box, and neither in it's coming in, nor in it's going out, will it be turned out of it's Way, as was ſaid in N. 2793.

EXPERIMENT 2.

2798. The ſame Things being ſuppos'd, let a Ray fall obliquely upon the Surface of the Box; the upper Part of the Ray will continue it's Motion through c to d in a right Line; but the lower Part in the Water, will be bent towards e , approaching towards the Perpendicular: Which confirms Number 2787.

EXPERIMENT 3.

2799. Things remaining as in the foregoing Experiments; the Ray which at e , paſſes out of the Water into the Air along fe , is turn'd out of it's Way in receding from the Perpendicular; and indeed in ſuch Manner, as to follow the ſame Direction with the Ray falling upon the Water at e ; for acd , ef are parallel. Which confirms Numbers 2788, 2789, 2792.

EXPERIMENT 4.

These Experiments answer in the same Manner, if instead of Water we make use of Glafs. Then we use another Box A D *; Pl. 89. F. 4. the open End of which is clos'd by the Board T †, as in the foregoing Experiments. Part of the Light passes through the Glafs Cube C *, and Part passes above it; if we make the three last Experiments this Way, the Event will be the same; but the Refraction is greater in the Glafs than in the Water.

To make the Way of the Light along the Air sensible to us, we put Flower into a Bag made of fine Linen, and tie up the Mouth of it. This is shaken, that the Flower may be dispers'd in that Place, along which the Light passes; which in passing along illuminates strongly the small Particles of the Flower, which come in it's Way.

In what has been said hitherto, we have only consider'd the Attraction of the more dense Medium, because this prevails; but the Action of the rarer Medium is not to be overlook'd, because this diminishes the Action of the denser Medium, which will be so much the less upon the Light, as the Mediums differ less from one another in Density. Therefore *there is no Refraction, when the Densities of the Mediums are equal; and it is the greater, the more these Densities differ from one another.*

The Laws of Refraction are deduc'd from the Acceleration, which the Attraction generates.

The Attraction obtains between the Planes, represented by the Lines G H and I L, and no farther *.

DEFINITION 7.

For this Reason we call the Space, terminated by these Planes, the Space of Attraction.

In the following Scholium we demonstrate that, although the Action of a Body upon Light be directed perpendicular to the Surface, the Acceleration of Light, in it's Motion from a more rare into a denser Medium, or the Retardation in a contrary Motion, is the same, in what Direction soever the Light be carried; the Acceleration, or Retardation, is indeed less in a more oblique Motion, but it lasts longer, which makes a Compensation.

Therefore, *there is a constant Ratio between the Velocities of Light in two given Mediums.* This may indeed be demonstrated, by applying here, what was demonstrated concerning the Descent of

heavy Bodies in the first Book ; but it is illustrated more in the said Scholium, in which we also demonstrate, that *in every Inclination of the incident Ray there is a constant, and immutable Ratio between the Sines of the Angles of Incidence and Refraction ; and that these Sines are inversly, as the Celerities in those Mediums.*

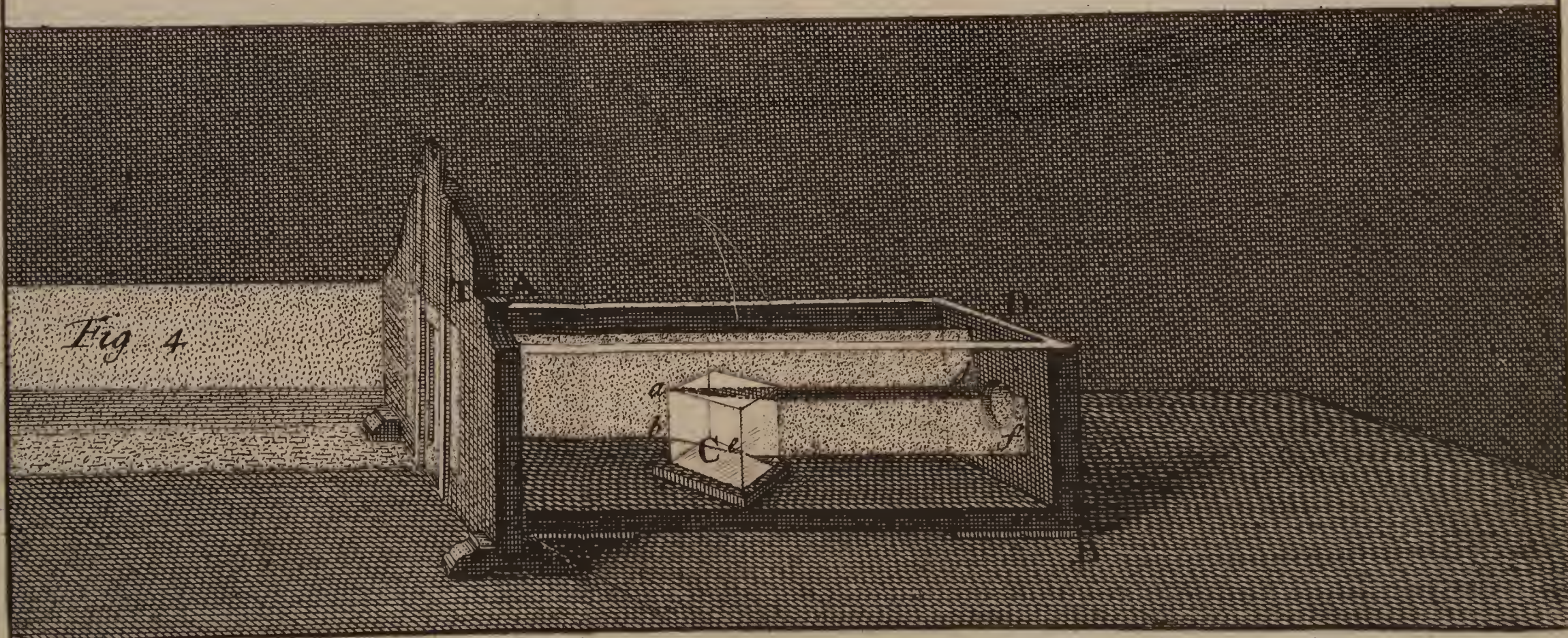
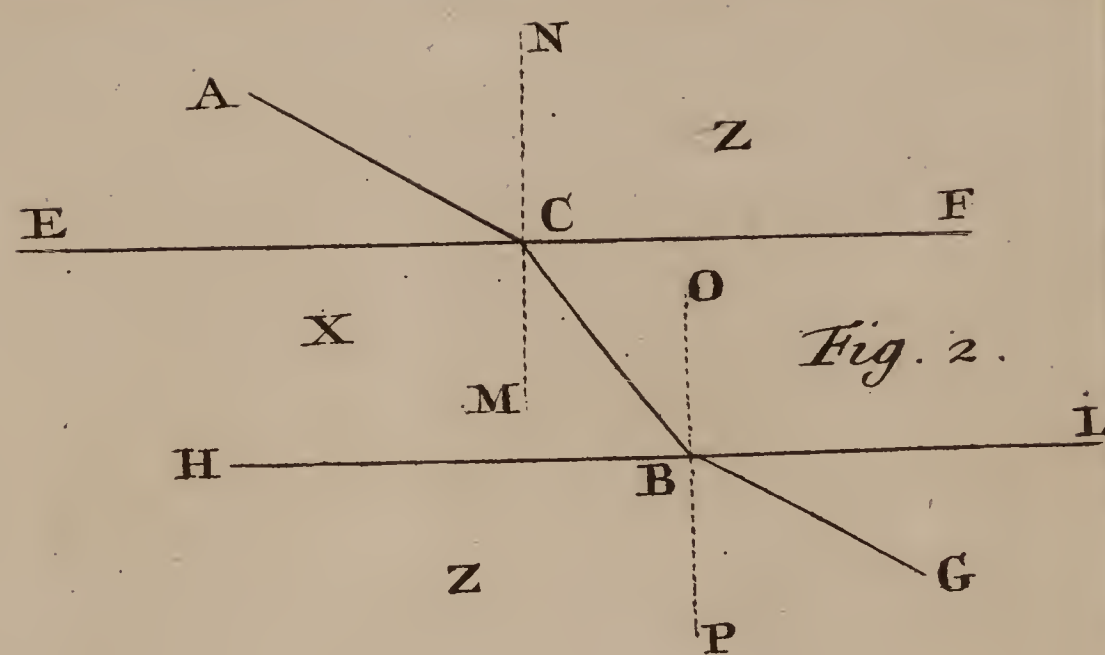
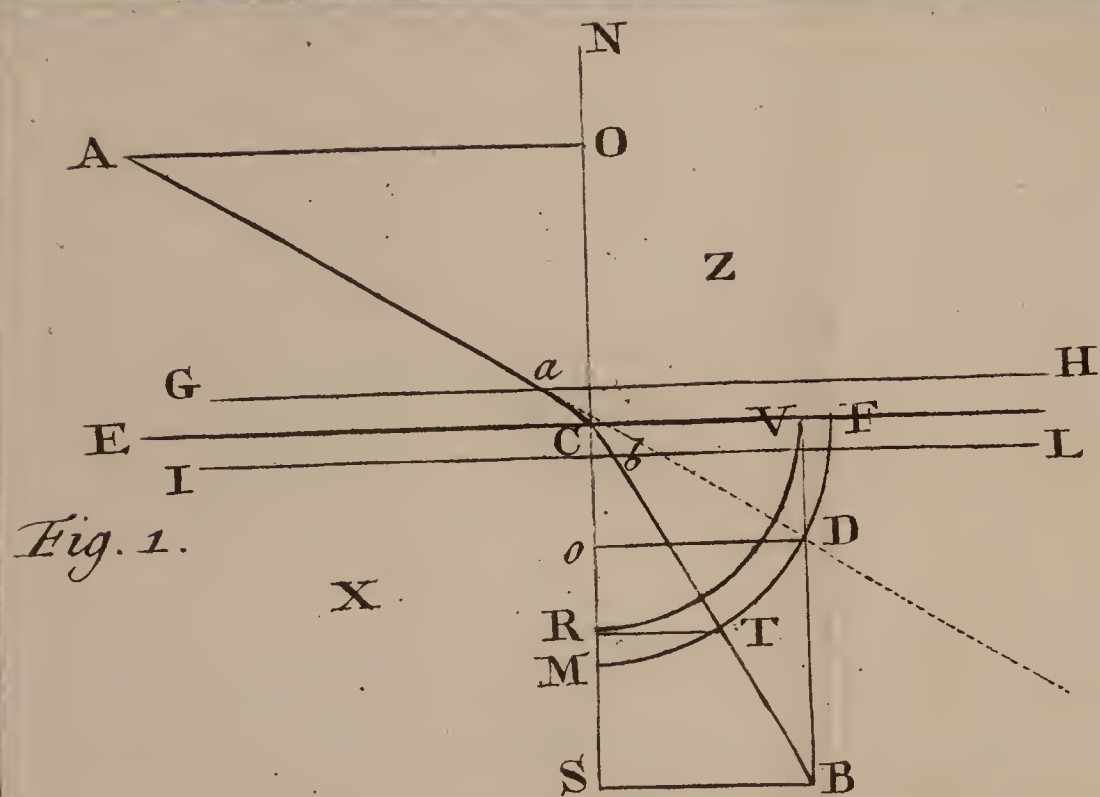
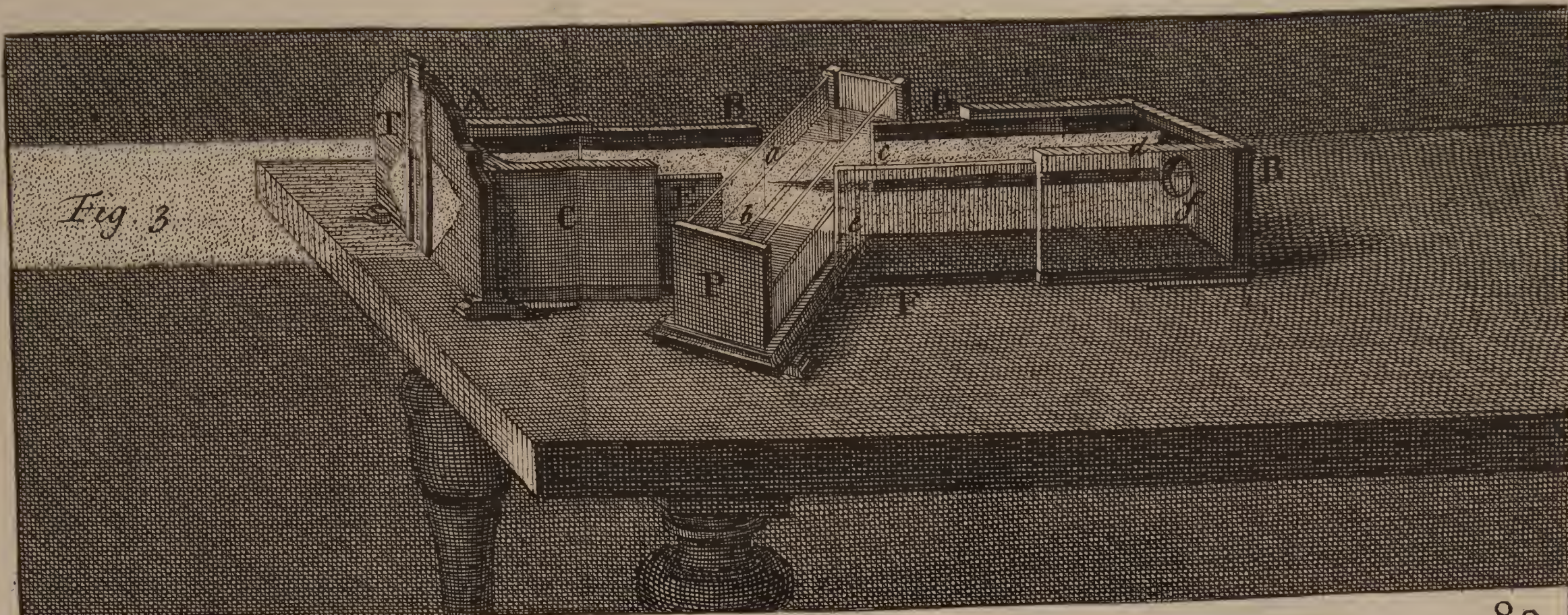
2811. If the Mediums be Air and Water, the said Sines are as 4 to 3, and the Celerities of Light in the Air are to it's Celerity in Water, as 3 to 4. But if, the Air remaining, the other Medium be Glais, the Sines are as 17 to 11 ; one Experiment will suffice to shew this with respect to all the Mediums.

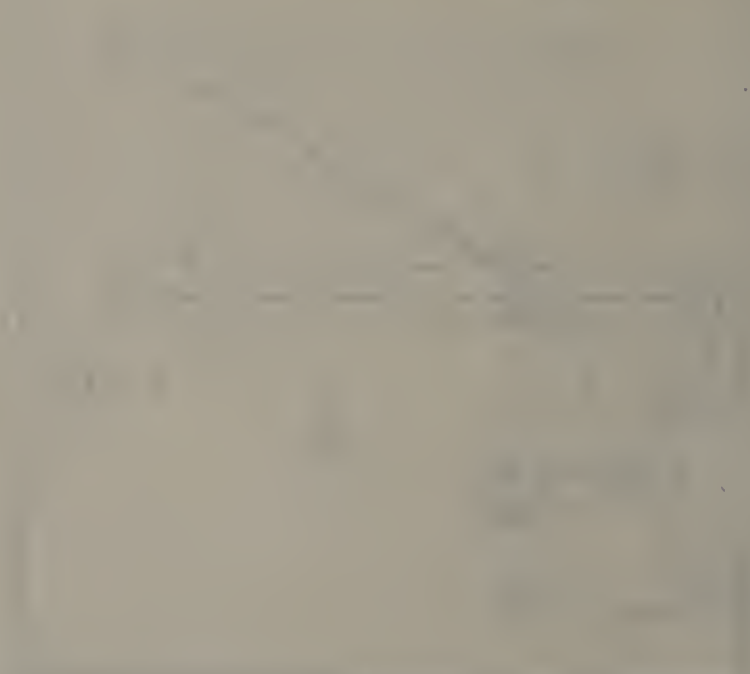
2812. The Angle DCM , is equal to the Angle of Incidence ACN *,
 * 15. El. 1. and the Quadrant of the Circle FDM being describ'd, the Sine of that Angle is Do ; the Sine of the Angle of Refraction BCM is TR ; the Ratio between these is constant. VDB being drawn parallel to CM , BS , which, with Do and RT , we suppose perpendicular to CM , is equal to Do * ; and the said constant Ratio will take Place between BS and RT ; as also, by Reason of the similar Triangles $BS C$, $TR C$, between BC , and TC *, or DC ; for these are Rays of the same Circle ; but if we suppose the Circle describ'd with the Center C , through the Point V , the Lines BC ,
 * 4. El. 6. DC , are *the Co-secants of the Angles of Refraction and Incidence ;* which therefore *are inversly as the Sines of the same Angles ;* which is the known Property of Co-secants.

2813. *It is confirm'd by the following Experiment, that there is a constant Ratio between the said Co-secants.*

EXPERIMENT 5.

2814. We make use of the same Box MI *, that was us'd in the first
 Pl. 90. F. 1. Experiment ; this, as in that Experiment, is half fill'd with Water ; the Light is transmitted through the same Board, as was in
 * 2758. 2759. the said Experiment. The Box is so dispos'd, that the Light may enter into it obliquely through the Glass Plate at the End of it ; the Ray passes through this Plate in the Line ab , the upper Part moves above the Water in a right Line along ac , and runs against the Side of the Box at c ; the lower Part is refracted along be , and strikes against the same Side at e . Howsoever the Incidence of the Rays be alter'd, ac is always to be , as 3 to 4, inversly as the Sines of the Angles of Incidence and Refraction from Air into Water *.
 * 2811. But these Lines ac , be , are Co-secants of the same Angles.





SCHOLIUM.

Demonstrations of the Laws of Refraction.

WE have seen that the Attraction of Light only takes Place in it's Passage along the Space of Attraction * ; therefore we must examine, what happens to Light in that Passage. 2815. *

*The Direction of the Action of the Medium upon the Light is perpendicular to the Surface dividing the Mediums * ; and therefore, in this Case, to the Surface IL ; and it is unequal at different Distances from this Surface * ; but at equal Distances it is equal ; because both Mediums are suppos'd homogeneous, and every where similar.* 2816. Pl. 89. F. 1. 2780. *

The Motion of the Ray AC may be resolv'd into two other Motions along AO and OC *, the first of which is parallel to the Surface EF, the second is perpendicular to the same Surface ; the Celerities of whose Motions will be respectively proportional to these Lines AO and OC, whilst AC represents the Celerity of the Ray itself *. 2817. *

The Motion along the Direction AO is not alter'd by the Attraction, perpendicular to the Surface IL, only the Motion along OC is accelerated. 2818. *

The Line AC being kept, namely the Celerity of the Ray itself, it's Inclination may be alter'd, whereby the Celerity along the Direction OC is also chang'd ; which Celerity is nothing, if the Angle AaG be very small. In which Case, if after the Ingrefs of the Light into the denser Medium, it's Motion be resolv'd into two in such Manner, that the Direction of the one be perpendicular to the Surface IL, it's whole Celerity will be to be attributed to the Attraction often mention'd. For in the Ingrefs into the Space of Attraction the Motion along this Direction is generated, which in the Passage along this Space, in which there is every where a new Action, acts upon the Light, in the same Direction, is continually accelerated. This Acceleration obtains in every Passage of the Light along the Space of Attraction, but is different according to the different Celerity, with which the Light comes perpendicularly to the Surface separating the Mediums. 2819. *

If the Attraction were equable through the whole Breadth of the Space of Attraction, what relates to the Acceleration mention'd, as we have demonstrated concerning the Acceleration of heavy Bodies *, might be determin'd by Means of the Right-angled Triangle PQR, in which the Lines, parallel to the Base, represent the Celerities, whilst the Portions of the Area of the Triangle represent the Spaces run through. But we here speak always of the same Space run through, namely the Breadth of the Space of Attraction, because we only consider the Motion perpendicular to the Surface separating the Mediums ; therefore this Space run through is always represented by equal Portions of the Area of the Triangle PQR. Let this Portion be Pdc, when the Light enters the Space of Attraction, in the said perpendicular Direction, with the Velocity o ; that is, when the 2820. Pl. 90. F. 2. *

the incident Ray makes the smallest Angle with the Surface separating the Mediums ; de in this Case will represent the Celerity acquir'd by the Attraction, and with which the Light goes out of the Space of Attraction.

2821.

If the Light enters the Space of Attraction perpendicularly, with the Celerity represented by fg , it will go out of that Space with the Celerity bi , the Arches Pdc and $fgib$ being put equal to one another, as appears from what has been said. The Triangles Pdc , Pfg , Pbi are similar ; and therefore their Archs are in a duplicate Ratio to one another ; that is, as the Squares of the homologous Sides dc , fg , bi * ; but the Sum of the Areas Pdc , Pfg is equal to the Area Pbi , (by Reason of the equal Areas Pdc and $fgib$;) therefore also the Sum of the Squares of the Lines dc and fg is equal to the Square of the Line bi ; whence it follows that the Triangle, form'd by these three Lines, is rectangular, and that it's Hypotenuse is bi *.

* 19. El. 6.

* 48. El. 1.

2822.

In a Right-angled Triangle, one of whose Sides is the Celerity, with which the Light enters into the Space of Attraction perpendicularly, and the other Side the Celerity acquir'd in running through this Space, when the Light enters into it with the Celerity o , the Hypotenuse of the Triangle represents the Celerity, with which the Light goes out of the Space of Attraction perpendicularly at the opposite Part. Which obtains universally, howsoever the Attraction be alter'd in the Space of Attraction according to the different Distance from the Planes, by which this Space is terminated. To prove which,

2823.

Pl. 90. F. 3.

Let us suppose the Space of Attraction to be divided into two Parts either equal, or unequal, by a Plane parallel to the Surfaces, by which it is terminated. Let us further suppose that there is a different Attraction in these Parts, but that it is not different in the same Part. These Parts are to be consider'd as two different Spaces of Attraction. Let A be the Celerity, which the Light acquires in running through the first Part of the Space, when it enters into that Space with the Celerity o ; let B be the Celerity, acquir'd in running through the second Part of that Space, when the Light enters this Part in like Manner with the Celerity o . It must be observ'd that in this Demonstration we every where consider the Motion perpendicular to the Surface, separating the Mediums.

Let the Light enter the first Part of the said Space with the Celerity o ; it will come to the second Part with the Celerity A ; if therefore the Right-angled Triangle ECD be form'd with the Sides A and B , the Hypotenuse ED will represent the Celerity, with which the Light will go out of the Space of Attraction *.

* 2822.

Plate 90.

Fig. 3, 4.

* 2822.

If the Light enters into the Space of Attraction with the Celerity FG , let the Right-angled Triangle HFG be form'd with the Sides FG and A ; the Hypotenuse HG will be the Celerity, with which the Light goes out of the first Part of the Space of Attraction *, and enters into the second ; but by forming the Right-angled Triangle HGI , whose perpendicular is equal to the Line B , there is given the Hypotenuse IG , representing the Celerity, with which the Light goes out of, and continues it's Motion after it has run through the whole Space of Attraction *.

* 2822.

But

But we must demonstrate, that the Celerity IG is also the Hypotenuse of the Right-angled Triangle NML , whose Side ML is equal to FG , the Celerity with which the Light enters into the Space of Attraction, and whose other Side, LN , is equal to the Line ED , the Celerity, which the Light acquires, in running through the whole Breadth of the Space of Refraction, when it has enter'd into it with the Celerity o ; which being demonstrated, it will appear that the Proposition of Number 2822, obtains in this Case also, in which two different Forces of Attraction act.

2824.

But it plainly appears from the Consideration of Right-angled Triangles that the Lines IG and NM are equal. The Square of the Line NM is equal to the Squares of the Lines NL and LM , or $FG:NL$, is equal to the Line ED , whose Square is equal to the Squares of the Lines EC and CD , or the Lines A and B , which are equal to the Lines FH and HI : Therefore the Square of the Hypotenuse NM is equal to the three Squares of the Lines FG , FH , and HI . To the same three Squares the Square of the Line GI is equal; for this is equal to the Squares of the Lines HI and HG ; which last is equal to the Squares of the Lines HF and FG .

If the Space of Refraction be divided into ever so many Spaces, by Planes parallel to the Surfaces, by which this Space is terminated, and different Forces of Attraction obtain in different Parts, the same Demonstration *will take Place*; and the Number of Divisions may be increas'd at Pleasure *in infinitum*; which is the Case *in the Refraction*, which Light undergoes in passing out of any Medium whatever into another of different Density *; to which therefore *the Rule of Number 2822*, may be * applied.

2825.

2816.

Let Z be the more rare Medium, X the denser, and let them be separated by the Plane EF ; let there be a Ray of Light AC , falling upon the Surface EF obliquely; let AC represent the Celerity of the Light in the Medium Z , and let this Line AC be constant; that is, let it remain, whatsoever the Inclination of the Ray shall be. Describe a Circle with the Center C , and Semidiameter CA ; let NCM be perpendicular to EF ; draw from A the Perpendiculars AO to NC , and AQ to EF .

2826.

Pl. 90. F. 5.

Let the Motion along AC be conceiv'd to be resolv'd into two others, one along AO , the other along AQ or OC *; the Line OC will represent the Celerity of the Ray perpendicular to the Surface EF , which Celerity alone is increas'd from the Attraction of the Medium *.

* 319.

* 2818.

Let CP be the Celerity, which the Light acquires in passing through the Space of Attraction of the Medium x perpendicularly, o being suppos'd the Celerity of the Light in it's Ingress; the Hypotenuse OP of the Right-angled Triangle PCO will be the Celerity of the Ray AC in the Medium X , in the Direction perpendicular to the Surface EF *; the Celerity of the Light in the Direction AO , or QC , parallel to the Surface EF is not alter'd *. Therefore let CV be equal to AO , or QC , and VB perpendicular to EF , equal to the Hypotenuse PO , and draw CB ; the Motion along CB will be the Motion compounded of the two, and this Line by it's Position determines the Direction, and by it's Length *the Celerity*,

* 2825.

* 2818.

2827.

* 318. *Celerity, of the Light in the Medium X* * ; which Celerity is not alter'd by the different Inclination of the Ray AC . For the Square of the Line CB is equal to the Square of the Line BV , or PO , and the Square of the Line CV , or AO ; but the Square of the Line PO is equal to the Squares of the Lines PC and CO ; therefore the Square of the Line CB is equal to the three Squares of the Lines PC , CO , and AO ; which two last if they be join'd, we shall have the Square of the Semidiameter AC , or CN ; that is, CB is equal to PN , whose Square is also equal to the Squares of the Lines PC and CN , and which is not alter'd when the Inclination of the Ray AC is chang'd.

The Line CB cuts at T the Circle describ'd with the Semidiameter CA ; draw from the Points B and T , BS and TR perpendicular to CM : By Reason of the similar Triangles CBS , CTR , BC will be to TC , or CA , as BS to TR ; which Lines therefore, by Reason of BC and CA being constant, will always be in the same Ratio, whatsoever the Angle of Incidence be. TR is the Sine of the Angle of Refraction TCR ; and BS , equal to CV , equal to AO , is the Sine of the Angle of Incidence ACO ; between which Sines therefore there is a constant Ratio, as was said in N. 2809.

2828. We have hitherto consider'd a Ray passing out of a rarer Medium into a denser ; but the same constant Proportion of the Sines obtains in a contrary Motion of the Rays ; the Angles ACN , MCB are not alter'd, whatsoever the incident Ray be, whether AC or BC *. In this Case if BC be the Celerity of the incident Ray, CA will be the Celerity of the refracted Ray ; for the Motion of the Ray passing out of X into Z is retarded in the same Manner, from the Attraction towards the Medium X , as it is accelerated in the contrary Motion.

* 2789.

CHAP. VI.

Of the different Action of different Bodies upon Light.

2829. **W**E have seen that all the Particles of Bodies act upon Light ; in the last Chapter we reason'd as if they all acted equally ; when this obtains, what was said, is always true, that the denser Medium attracts Light more strongly than the rarer ; and that therefore the Refraction from the rarer Medium into the denser is towards the Perpendicular * ; in this Case also the refracting Force follows the Ratio of the Density of the Body. We consider'd the Thing in this Manner, because we thought it best to bring it to the greatest Simplicity, at the first Examination.

* 2787.

2830. This indeed is the Case in many Bodies ; in Air, Glass of Antimony, the Selenites, common Glass, Mountain Crystal, and in
2831. many

Chap. 6. of Natural Philosophy.

I 37

many other Bodies, the refracting Force is sensibly as the Density; but this is not a general Rule. 2832.

But the Particles of several different Bodies act differently upon Light; but they may be reduc'd to different Classes, in each of which the Rule mention'd * takes Place. 2833.

Such a Class has been just mention'd *. *Unctuous Bodies make another Class*, to which we reduce Camphire, Oil of Olives, Linseed Oil, Spirit of Turpentine, and such like Bodies. * 2831. 2834. 2830.

In all these the refracting Force of all the Particles is sensibly the same, and this very much exceeds the Force which obtains in the foregoing Class *. 2835. * 2830.

Many Bodies consist of Particles whose Action upon Light is intermediate, and which may be brought to intermediate Classes when the Refractions of many Bodies shall be determin'd. 2836.

Sir *Isaac Newton* determin'd the Force, with which Particles act, in twenty two Bodies; and the Table, which he has given relating to them in his Opticks, might be extended to many other Bodies, if for all, one Experiment only concerning Refraction be made. But how the Force of the Particles is collected from the Experiments concerning Refraction, the Density being given, will be explain'd in the next Scholium. 2837.

Hence it follows that all, that was said concerning Refraction in the last Chapter, may be applied to all the Classes; but this does not always obtain in the Passage of Light from a Body of one Class into a Body of another, as appears from the following Experiments. But how the Propositions are to be alter'd to make them universal, I shall now say. 2838.

All the Reasoning, laid down in the last Chapter, is founded upon the Attraction of Light by Bodies; and we have demonstrated that there is a Refraction, when the Attraction is greater on one Side, than on the other; wheresoever this obtains, the Demonstrations take Place; but this obtains, as often as one of two Contingent Mediums acts more strongly upon the Light than the other. Therefore *the Demonstrations will be general, if, what was said of a denser Medium, be applied in general to the Mediums whose Action upon Light is greater.* 2839. 2840.

But *this Action is as the Force, with which all the Particles act, and as the Number of Particles acting together, that is, as the Number of Particles, contain'd in a certain Space; which Number is as the Density of the Body,* 2841.

For except we correct the Propositions thus, that were deliver'd in the last Chapter, which, as they are commonly found in Optick Writers, we have also given, many of them will be false.

2842. For *Light may undergo a Refraction*, in it's Passage out of one Medium into another, *although the Mediums do not differ in Density*, which is contrary to Number 2778.

2843. In the Passage of Light, out of Alum into Vitriol, the Refraction is towards the Perpendicular, the Sine of Incidence is to the Sine of Refraction, as 26 to 25; yet the Densities are equal; but the Forces, with which the Particles of these Bodies act upon Light, are to one another as 20 to 23.

2844. *Light may pass* out of one Medium into another, in any Direction whatever, *without any Refraction*, though the Mediums differ in Density; which does not agree with N. 2779.

EXPERIMENT I.

2845. We pour Oil of Olives into a Glass; if this be cylindrical or conical, the Figures of the Objects, seen through the Oil, appear alter'd, but they are distinct. Moreover we make use of a Piece of Borax, very transparent, but whose Figure is so irregular, and it's Surface so unequal, that the Objects will not appear through the Borax, without being very much confus'd, so that they cannot be known; or rather, that we may perceive nothing besides the Light, which enters into the Eyes irregularly.

When we immerge this Piece of Borax in the Oil, we perceive Objects in the same Manner through the Oil and Borax, as through the Oil alone; the Borax becomes in a Manner invisible, and if there be any thing in the Borax, we perceive it, as if it were in the Oil.

2846. Therefore the Light passes in a right Line from the Oil of Olives into the Borax, and from the Borax into the Oil; and there is no Refraction here, although the Density of the Oil is to the Density of the Borax as 6 to 11; but the Actions are in this inverse Ratio, with which all the Particles act upon the Light, and there is a Compensation made *.

* 2841.

2847. *Light often in it's Passage out of a more dense Medium into a rarer is refracted towards the Perpendicular*. Which is contrary to Number 2787.

EXPERIMENT 2.

We make use of the Glass Box M I *, which has been often
us'd; into this we put the smaller Glass Box P (Fig. 7.) whose
Bottom is of Brass, and whose Construction is not different from
the Construction of the greater Box before explain'd †.

2848.

Pl. 90.

Fig. 6, 7.

* 2758. 2759.

Instead of this smaller Box we may use a polygonous Phial whose
upper Part is cut, as is represented at O (Fig. 7.) But in this Case,

† 2759.

2849.

that we may avoid the irregular Reflections of the Light, as much
as possible, the external Surfaces of the Bottom, and Sides, must
be made rough by rubbing on them coarse Sand, that they may re-
ceive a black Colour. We only leave the two greater, and oppo-
site Sides *m* and *n* untouch'd, through which the Light must pass.

This Box has this Inconveniency, that the Light can never pass
through the Sides of the Box quite regularly; because the inner
Surfaces are never entirely plane; which Inconveniency is never-
theless scarce sensible when Spirit of Turpentine is pour'd in, whose
refracting Force is very great.

Water is pour'd into the Box I M to any Height; Spirit of
Turpentine is pour'd into the Box P to the same Height.

2850.

The Light is transmitted through the Board *, which was made
use of in the Experiments of the last Chapter; the Light is let into
the larger Box at *a b* through the End M L, perpendicularly to the
Surface; the Light enters into the Box P, which is set obliquely at
c d; *c d* is in the Side *g* of the smaller Box, a little distant from the
End, and the Light enters into the Oil very obliquely; it is re-
fracted at *e f*, approaching towards the Perpendicular. We have
not represented the Ray going out of the Box P, to avoid Confusion.

* 2768.

The Density of Water is to the Density of Spirit of Turpentine,
as 8 to 7. The Sine of Incidence in Water is to the Sine of Re-
fraction in the Spirit, as 11 to 10. Lastly the Force, with which
the Particles of Water act, is to the Force of the Particles of the
Spirit of Turpentine, as 3 to 5.

2851.

When we compare the Forces, with which all the Particles of
Bodies act, we consider such Particles, as contain equal Quantities
of Matter; but we don't mean the smallest Particles, into which
Bodies may be resolv'd; for who can determine whether all these
are equal or not; and whether the Action upon Light may not be
varied, from the Disposition of the smallest Particles among Particles
of a superior Order?

2852.

2853.

We also measure *the Forces of all the Particles*, by considering their whole Action upon Light, whilst it passes through the Space of Attraction; that is, *we compare* the whole Effects of the Attraction, and reason *as if all the Spaces of Attraction were equal*, which perhaps is not true; but this does not alter the Conclusions, which may be of use in explaining Phenomena.

2854.

When Light passes out of one Body into another, the Difference of the Forces only is to be consider'd; but we speak of the whole Forces of Bodies, which we have by multiplying the Densities by the

* 2841.

Forces of all the Particles *. In this Case a smaller Action, acting contrary to a greater, diminishes it.

2855.

When Light passes through different Mediums, terminated by parallel Planes, the Direction in the last Medium is the same, as if the Light had pass'd out of the first Medium immediately into the last.

For in each Case the whole bending Force is the same. The Difference between the Force of Air and the Force of Water, is to the Difference between the Force of Air and the Force of Glass, nearly as 14 to 25. If the Light passes immediately out of Air into Glass the bending Force will be equal to 25; but if the Light passes out of Air, through Water, into Glass, two Actions act successively, the first of which is equal to 14; the second is equal to the Difference between the Actions of the Water and Glass *, which is 11; and the Actions together are also equal to 25. If the Number of the Mediums put between be greater, the Demonstration is the same; all the Differences of the intermediate Actions together are equal to the Difference of the Actions of the extreme Mediums. We suppose the Mediums to be terminated by parallel Planes, that all the Directions of the Actions may agree *.

* 2854.

* 2780.

2856.

From hence we conclude that the Refraction out of one Medium into another may be determin'd, though there be no Experiments concerning such a Passage; which will be sufficiently illustrated by one Example only.

2857.

Let us suppose the Sine of Incidence to be to the Sine of Refraction out of Air into Water, as 4 to 3: And that these Sines out of Air into Glass are, as 17 to 11, as has been observ'd before *; I want to know the Ratio between these Sines, when the Light passes out of Water into Glass. If the Light shou'd pass out of Air into Glass through Water, the Sine of the first Incidence wou'd be to the Sine of the second Refraction, in the Ratio of 17 to 11. We ought to take away from this the first Refraction, in which the Ratio of the Sines is, as 4 to 3. By multiplying the

* 2811.

Antecedents

Antecedents and Consequents we join the Ratios, which take Place together ; after the same Manner by Division we separate the Ratios, when one is to be taken from the other ; therefore the Ratio sought is that, which is given between $\frac{1.7}{4}$, $\frac{1.1}{3}$, that is, the Sines, of which we are speaking, are to one another, as 51 to 44. For this Ratio is requir'd, that the whole Inflection may be the same with that, which takes Place, when the Light goes immediately out of the Air into the Glass.

S C H O L I U M.

WE said that from the Experiments concerning Refraction the Proportions of Forces were determin'd, with which the Particles of Bodies act upon Light * : I shall now shew how this is done ; but first I shall speak of the Forces of the Bodies themselves, and then of the Forces of all the Particles. 2858. 2837.

When we treat of the whole Forces of Bodies, the Light, which passes out of empty Space into Bodies, must be consider'd ; for if Light passes from one Body into another, we can only discover the Difference of the Forces of those Bodies * ; but all Cases may be resolv'd by the same Rule. 2859. 2854.

We have already said that it was unknown to us, whether all the Spaces of Attraction be equal or not * ; we must moreover add, that it is also unknown to us, whether the Action, which is different at different Distances from the Surface of the Body, be alter'd according to the same Laws, in the Spaces of Attraction of all Bodies. But as the whole Effects alone, that is, the Alterations only, which obtain in the Passage through the Space of Attraction, are discover'd by us, we may reason, as if the same Laws obtain'd every where ; in the same Manner as we suppos'd the Breadths of the said Spaces equal *. But if the same Laws take Place, *the Forces are to one another, as they wou'd be, if they acted uniformly through the whole Spaces*, and we ought to Reason concerning these Forces as of any accelerating Forces whatever, which increase their Celerities uniformly, and act through equal Spaces. 2853. 2860.

Let us suppose two Bodies, one of which descends vertically through AB, the other rolling down the inclin'd Plane AD ; both these Bodies are accelerated equably ; but they are driven with unequal Forces. 2861. Pl. 90. F. 8.

Let us suppose one to have come to B, and to be carried with the Velocity acquir'd in falling through AB, and to be accelerated in descending beyond BC ; we suppose the second Body to have come to D, and to be carried with the Velocity, acquir'd in running through AD, and to be accelerated in descending beyond DE, equal to BC. From the given Velocities the Forces are sought.

Draw Dd , Ee , horizontal ; the accelerating Forces will be as AD to Ad , or AE to Ae * ; that is, as DE or BC , to de †. The Velocities at D and d , 341. † 17, 18. El. 5.

* 390. D and d , as also at E and e , are equal * ; therefore the four given Velocities, are those, which the Body would acquire in falling through AB, AC, Ad and Ae ; and in this Ratio are the Squares of these Velocities *.
 * 374. Therefore BC, is to de , that is, the Force, that accelerates the first Body, is to the Force, acting upon the second, as the Difference of the Squares of the Velocities of the first Body to the Difference of the Squares of the Velocities of the second Body.

2862. If we apply this to Light, we have this general Rule ; *The Force, that accelerates Light, whilst it passes from one Medium into another, is to the Force, which takes Place in another Passage, as the Difference of the Squares of the Velocities before and after the Ingress, in the first Motion, to the like Difference in the second.*

2863. We have seen above that the Velocities of Light in Air and Water are to one another, as 3 to 4 ; the Velocities of Light in Air and Glass, as
 * 2811. 11 to 17 *. The Sine of the Incidence is to the Sine of Refraction in the Motion from Air into Spirit of Turpentine as 25 to 17 ; and therefore
 * 2810. the Velocities in these Bodies are as 17 to 25 *. From hence we deduce that the Velocities of Light in Air, Water, Glass, and Spirit of Turpentine, are to one another as 1000, 1333, 1547, 1470. The Velocity of Light in Air differs little from the Velocity in Vacuo, and unless we use greater Numbers, the Difference can't be express'd ; therefore we suppose the Velocity of Light in Vacuo to be 1000 also.

Now if any one seeks the Ratio between the whole Force of the Glass and the Action, which acts upon the Light, when this passes out of Water into Spirit of Turpentine, this Ratio is that, which is given between the Difference of the Squares of the Numbers 1547 and 1000, to the
 * 2862. Difference of the Squares of the Numbers 1470 and 1333 * ; which Differences are as 1388 to 358.

The Forces of Bodies being given, the Forces of the Particles are easily discover'd ; for as those are in a Ratio compounded of these last Ratios and the Densities, it is manifest, that *the said Forces of the Bodies must be divid d by the Densities, that the Quotient of the Divisions may express the Forces of the Particles.*

2864. From the Squares of the Velocities of Light in Water, Spirit of Turpentine, and Glass, I subtract the Square of the Velocity in Vacuo, and the Differences are as 778, 1163, 1388, which express the Forces of the
 * 2862. Bodies * ; these being divided by the Densities of those Bodies, which are as 40, 35, 103, we have the Forces of the Particles as 195, 333, 135.

2866. The Force, that accelerates Light in it's Passage out of a less refracting Medium into a more refracting one, retards the Motion in the contrary
 * 2828. Passage * ; whence it follows, that what is demonstrated in this Scholium concerning the Acceleration of Light, may be applied to the Retardation of it, *mutatis mutandis*, when the Light passes out of a more refracting Medium, into a less refracting one.

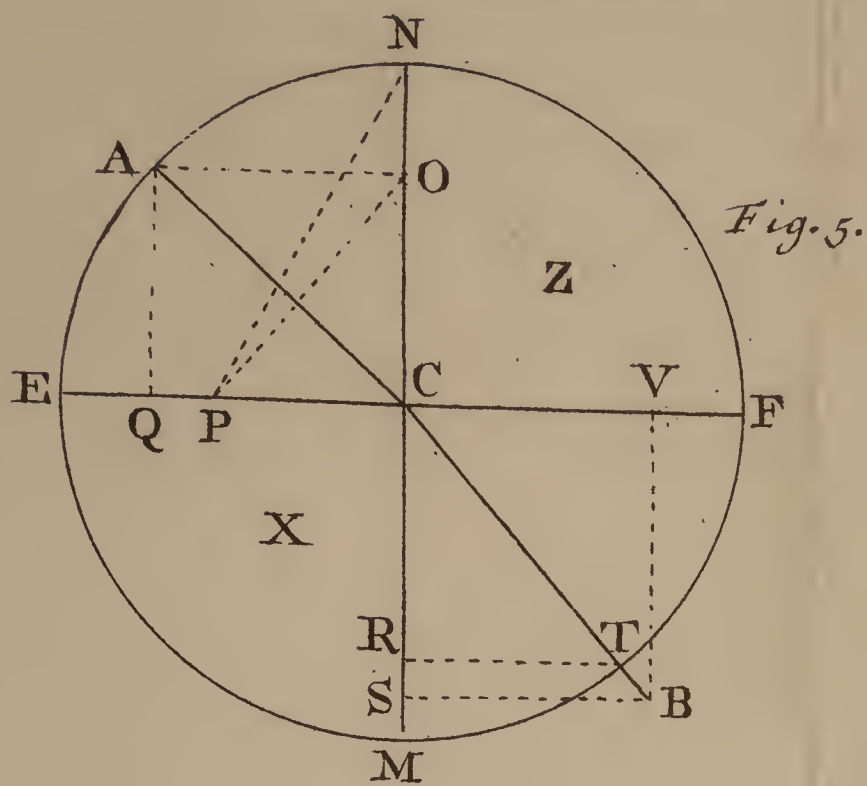


Fig. 5.

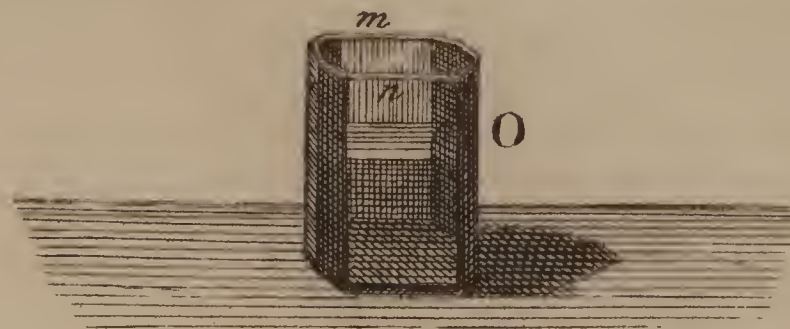


Fig. 7.

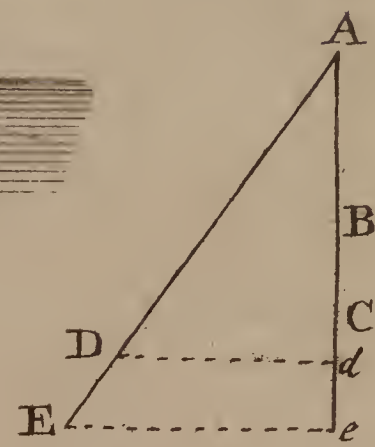
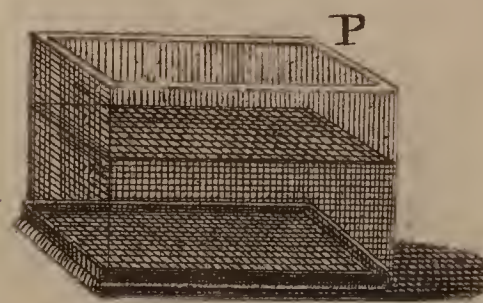


Fig. 8.



A B

Fig. 3.

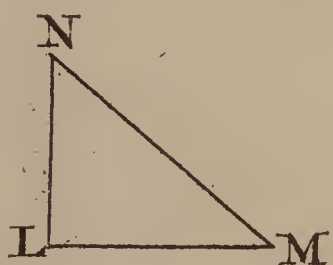
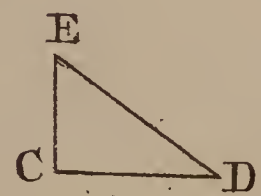


Fig. 4.

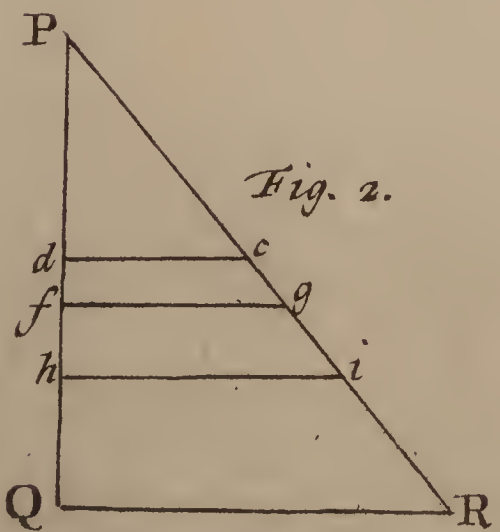
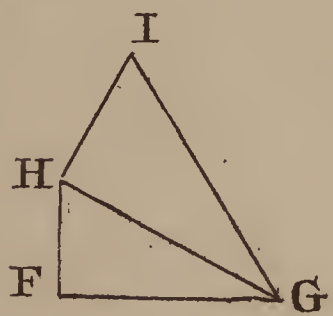
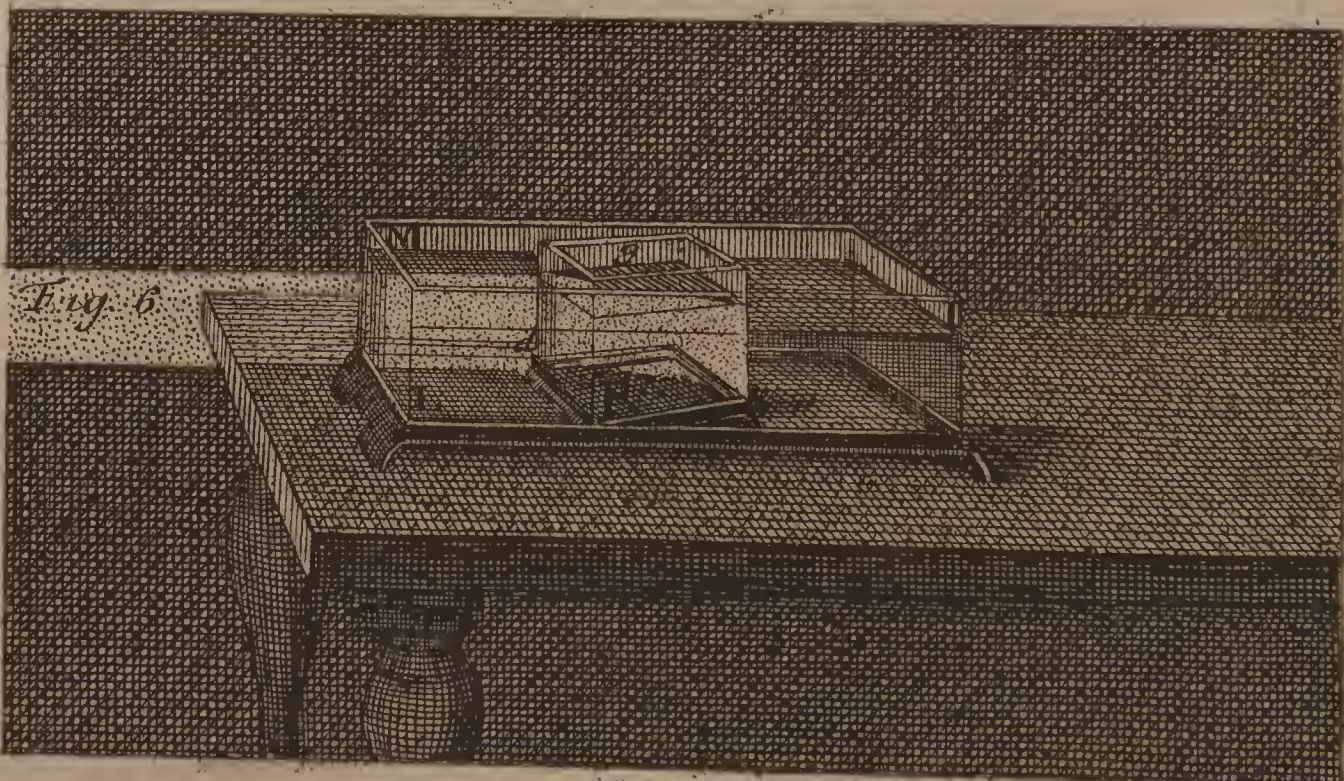
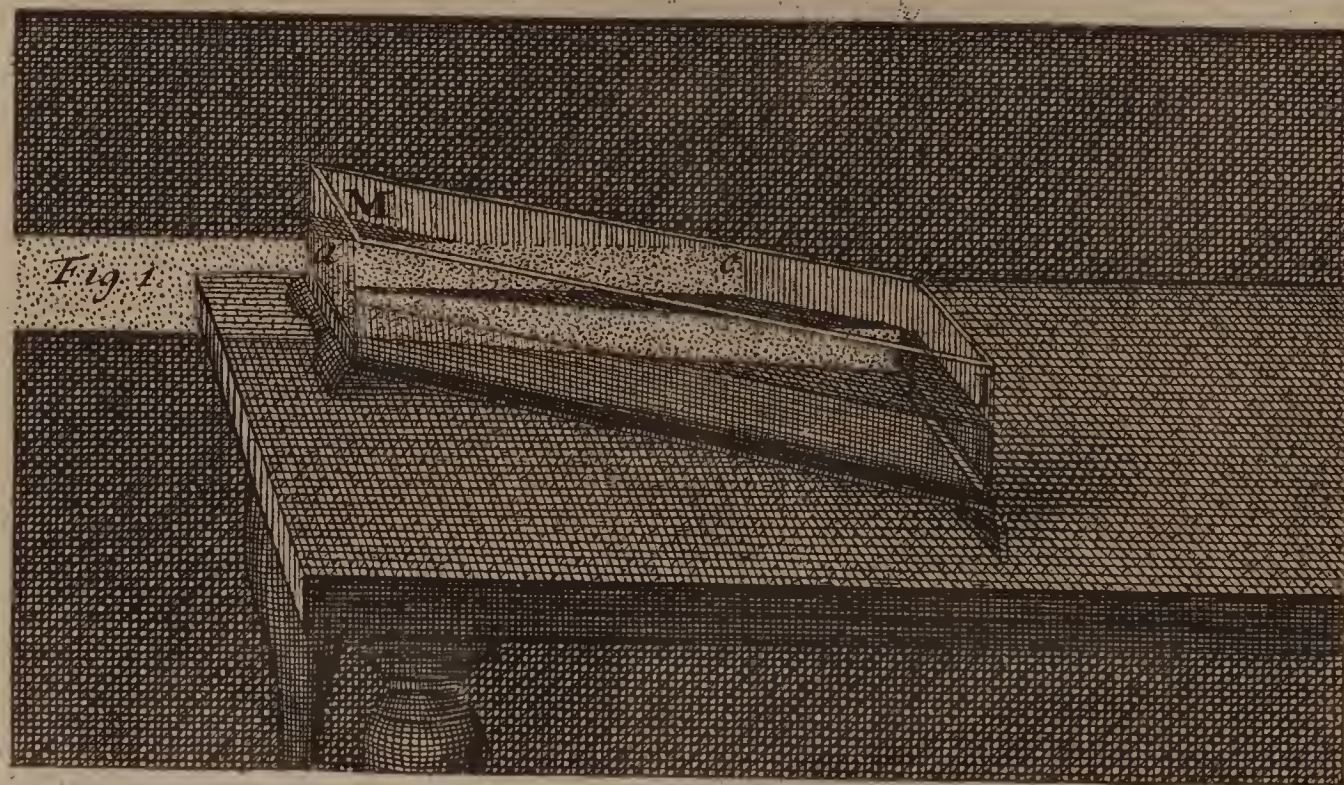


Fig. 2.



C H A P. VII.

Of the Refraction of Light, when the Mediums are separated by a plane Surface.

THE Surfaces, that separate the Mediums, may be varied in *infinitum*; we shall only examine those that are plane and spherical. In the Rays also there may be Variations in *infinitum*; we shall only consider those Rays, which proceed from one Point, or tend to one Point, or are parallel. All these Things being consider'd, we shall be able to explain the chief Phenomena of Light. 2867.

DEFINITION 1.

The Rays proceeding from one Point, or which are mov'd, as if they proceeded from one Point, are call'd diverging Rays. 2868.
Such Rays are continually dispers'd more and more.

DEFINITION 2.

The Point, from which the diverging Rays proceed, is call'd the radiant Point, or simply the Radiant. 2869.

The Rays sometimes move by Reflection, or Refraction, as if they proceeded from a Point, though they do not proceed from it, which we said were call'd diverging Rays also *. In this Case, * 2870. 2868.

DEFINITION 3.

The Point, from which the diverging Rays seem to come, is call'd the Point of Dispersion of such Rays. 2871.

DEFINITION 4.

Those Rays are more diverging, that make a greater Angle. 2872.

The more diverging the Rays are, the Distance between them being suppos'd the same, the less distant is the radiant Point, or the Point of Dispersion, and the contrary. 2873.

DEFINITION 5 and 6.

The Rays that meet in one Point, or wou'd meet if continued, are call'd converging Rays; and those are more converging, that make a greater Angle. 2874.

DEFINITION 7.

2875. *The Point of Concourse of converging Rays is call'd the Focus.*

DEFINITION 8.

2876. *The Point in which the Rays, that converge, and are intercepted, or bent before their Concourse, wou'd meet if continued, is call'd the imaginary Focus of these Rays.*

2877. *The more Rays converge, supposing the Distance between them to be the same, at the less Distance is the Focus, whether the true or imaginary one.*

We only consider those diverging, or converging Rays, that are a little dispers'd, that is, which, in their Passage from one Medium into another, take up a small Space in the Surface that separates the Mediums.

DEFINITION 9 and 10.

2878. *If among these Rays there be one Perpendicular to the said Surface, the Rays are said to be direct; in every other Case they are said to be oblique.*

2879. *If parallel Rays pass out of any Medium whatever into another of a different Refrangibility, these being separated by a plane Surface, after the Refraction they are parallel also: Because they are all equally bent.*

EXPERIMENT I.

2880. In this Experiment, as in all of this Chapter, we let the Light
 * 2794 2795. into a dark Place, as has been before explain'd *. We intercept
 † 2769. the Rays with the Board †, and only transmit some of them through an horizontal Slit, which is determin'd at Pleasure. We
 * 2758. 2749. make use of the Box terminated by Glass Planes *, and dispos'd
 † 2796. 2767. as in the first Experiment of the fifth Chapter †; or we make use of the Glass solid *, dispos'd as in the fourth Experiment of the same Chapter. Howsoever the Rays enter the Water or Glass, or go out of these Bodies, if they all pass through the same Surface, they remain parallel.

2881. Let there be the Mediums X and Z, this the less, that the more
 Pl. 91. F. 1. refracting, separated by the Plane ES; let the diverging Rays RC, Rb, Ra, proceed from the Point R, and enter the more refracting Medium: Among these let RC be perpendicular to the
 2 Surface

Surface ES ; this is not turn'd out of it's Way *, and it continues * 2793.
it's Motion along CG . The Rays Rb , Ra , undergo a Refraction
towards the Perpendiculars, which we suppose drawn to the Sur-
face ES in the Points b and a .

We easily determine the Refraction of any such incident Ray. 2882.
Let RM be a Ray proceeding from R ; ORC the Perpendicular,
through R , to the Surface separating the Mediums; take MO ,
and let it be to MR , as the Sine of Incidence to the Sine of Re-
fraction; that is, as the Co-secant of Refraction to the Co-secant
of Incidence *. By this being applied from the Point M , in the * 2813.
Angle MCR , the Point O is determin'd; from which the Line
 MN must be drawn through M , and this will co-incide with the
refracted Ray.

YMV being drawn perpendicular to ES , at M , the Angle of 2883.
Incidence is VMR ; the Angle of Refraction is YMN , to which
 VMO is equal *. If we suppose a Circle describ'd with the * 15.El.1.
Center M , and Semidiameter MC , the Lines MO , MR , will be
Co-secants of the Angles of Refraction and Incidence; whence it
appears that the refracted Ray MN was well determin'd.

But if the diverging Rays be direct, and a little dispers'd, such 2884.
as we have shewn the Rays RC , Rb , Ra , to be, we reason in
the same Manner; Ra , ra , being suppos'd to be in the said Ratio
of the Co-secants, aA will be the refracted Ray; but as Ca is
small, the Rays Ra , RC , do not differ as to Sense, neither do
 ra , rC ; therefore RC , rC , are also in the same constant Ratio
of the Co-secants, wherefore the Ray Rb , as also the rest a little
dispers'd, are refracted as if they proceeded from the same Point r ,
and r is the Point of Dispersion of the refracted Rays.

And in this Case, in which the Rays pass from a less refracting 2885.
Medium into a more refracting one, the diverging Rays become less
diverging *; and the Distance of the Radiant from the Surface is * 2872.
to the Distance of the Point of Dispersion, as the Sine of Refrac-
tion to the Sine of Incidence.

EXPERIMENT 2.

We close the open End of the Box AD * with the Board T †. 2886.
The Rays, which pass through the Glass V are converging, they Pl. 101.
mutually intersect one another at R , and become diverging. We Fig. 2.
don't enquire here, how the Glass produces this Effect, we shall * 2765.
speak of this Motion of Light in it's proper Place; it is sufficient † 2770.
that there are diverging Rays, that we may demonstrate the Ex-
periment.

We let these diverging Rays enter directly into the Glass solid
 * 2767. C*, and we immediately perceive the Rays to move in the Cube, as if they proceeded from a more distant Point.

2887. We reason about converging Rays in the same Manner. Let
 Pl.91.F.1. P Q be a Ray, which, supposing the same Medium Z and X, is directed towards a given Point f ; T f D H being drawn through f , perpendicular to the Surface separating the Mediums, if Q T be to Q f , as the Co-secant of Refraction to the Co-secant of Incidence, Q T will be the refracted Ray, as follows from what is demonstrated before *.

* 2883. If the Rays be direct, a little dispers'd, and converging, and pass
 2888. into a more refracting Medium, they become less converging. The Rays, among which H D, as I i, L l, which are directed to the imaginary Focus f , meet at the true Focus F, at a greater Distance;
 * 2884. which appears, if we reason as about diverging Rays *.

EXPERIMENT 3.

2889. This Experiment is made as the foregoing; the Situation of the
 Pl.91.F.3. Glass Cube C is alter'd, and the Glass of the Board is rais'd in such
 * 2771. Manner *, that the Rays may pass over the Cube; these meet at f , and this Point of Concourse remains at the same Distance from the Board, whether the Glass be rais'd or depress'd.

But this being depress'd in such Manner, that the converging Rays may enter into the Cube, the Concourse is immediately remov'd as far as F.

2890. The Rays are mov'd along the same Lines, from what Part
 * 2789. soever they proceed *; therefore from the Demonstrations concerning Motion, out of a less refracting Medium into a more refracting one, we deduce what relates to contrary Motion.

2891. The diverging Rays in a more refracting Medium X, proceeding
 Pl.91.F.1. from a Point F, are mov'd, in a less refracting Medium Z, as if
 2892. they proceeded from f , that is, they become more diverging; the converging Rays, which tend to r , meet at R, and become more converging.

EXPERIMENT 4.

2893. All Things being order'd as in the two last Experiments; the
 Pl.91.F.4. Glass Cube C is so plac'd, that the radiant Point R, which the Rays passing through the Glass of the Board T make, may be in the Surface of the Cube; then the diverging Rays pass through the Cube, and entering the Air are dispers'd more.

EXPE-

EXPERIMENT 5.

All Things remaining, as in the foregoing Experiment, move the Cube C to the Board T in such Manner, that the converging Rays may pass through the whole Cube; they then become more converging in the Air, and meet at F, at a smaller Distance than if they had continued their Motion, as they move in the Glass. 2894. Pl. 91. F. 5.

If the Rays, although direct, be too much dispersed, what we said of the Points of Dispersion, or the Focusses, cannot be applied to the Points; but a small Space is conceiv'd, through which the Rays pass, which is the greater, the more the Rays are dispers'd. 2895.

What relates to oblique diverging Rays, or converging, is more difficult; therefore we shall only mention it, and demonstrate it in the following Scholium. 2896.

Let BE be the Separation of the Mediums Z and X, that of the less, this of the more refracting one. We suppose the Plane of the Figure to be perpendicular to the Surface BE, as it always is, when the Surface is represented by a Line. 2897. Pl. 91. F. 6.

Let us suppose Rays, a little dispers'd, to proceed from A; and among these AB to be given; and that therefore they pass obliquely out of Z into X; CAE being drawn perpendicular to BE, through A, let the Point D be sought, through which the refracted Ray BI would pass, if continued downwards*; the Point of Dispersion of the refracted Rays will be in this Line at F, which Point is determin'd by the following Construction. * 2882. 2887.

We draw EH, EL perpendicular to AB and DB, from E; through H, where the Perpendicular to the incident Ray cuts it, we draw HN parallel to AE, cutting the other Perpendicular at N; the Points N and D being join'd, we draw LC parallel to ND, which meets DE continued at C; CF being drawn parallel to BE, the Point sought F will be given in the Concourse of this Line with the Line BD, it being produc'd as much as is necessary. 2898.

We shall demonstrate in the following Scholium, that the neighbouring Rays AB, Ab, are refracted along BI, bi, as if they proceeded from F; but the Demonstration only regards the Plane of the Figure. But we suppose Rays proceeding from A to be so dispers'd, as that they may make a Cone or Pyramid. Now if we conceive another Plane, that passes through the Line CAD, and makes a small Angle with the Plane of the Figure, this Plane will pass through the said Cone or Pyramid; that is, some of the Rays, proceeding from A, will be in this Plane; for these, a Point as F, 2899. Pl. 91. F. 7.

will be determin'd in the last Plane by help of the same Point C; and all the Points as F, which are found for the whole Cone or Pyramid, make a small Portion of the Circumference of a Circle, whose Center is C, and which is parallel to the Surface E B; and this small Portion of the Circumference may be look'd upon as a small right Line, perpendicular to the Plane of the Figure.

2900. Where we spoke of direct Rays, we consider'd four Cases*; we
 * 2885.2888. have now applied one of these to oblique Rays only; but the De-
 2891.2892. monstrations may be applied to all Cases. What was said of the Rays A B and D B, belongs to any incident Ray whatever with it's refracted Ray, whether this be the refracted Ray itself, or only a Continuation of it, as in the present Example; also it matters not, whether the Angle of Incidence exceeds the Angle of Refraction, or the contrary, the same Construction may take place, and the other Demonstrations obtain in the same manner.

2901. Therefore in General we infer, that *oblique Rays, whether diverging or converging, that pass out of one Medium into another, these being separated by a plane Surface, do not move after Refraction as if they proceeded from a Point, nor as if they tended towards one Point; that is, that there is no Point of Dispersion, or Focus of the oblique Rays; how little soever the Rays are dispers'd.*

2902. In these Cases, as was said of direct Rays too much dispers'd*,
 * 2895. for the Point of Dispersion, or Focus, we have a small Space, through which all the Rays pass; but we must determine where this ought to be plac'd. As at F the Rays pass through the small Line, so also at D, and between these Points is the Place sought.

2903. If this Line be cut by a plane Perpendicular to D F, the small
 Fig. 6. Space, of which we are speaking here, will in this Plane have the Figure of a Rectangle, whose Sides will have a different Ratio to one another, according to the different Place, in which this Plane is fix'd. But there is no Reason why we should chuse a small Space whose Height exceeds it's Length, than the contrary; therefore this Plane must be conceiv'd in that Place, in which the Space is a Square, and we shall have this Place for the Point of Dispersion, or Focus of the Rays: This Place is different according to the different Dispersion of the Rays, proceeding from A.

2904. Let us suppose the Rays proceeding from A, to make a right Cone; take B P equal to E H, and E Q equal to E L; draw Q C and P D, which last, continued, cuts F C at S. Through D draw a parallel to B E; and from the Point T, in which that cuts Q C,
 another

another Line TS must be drawn; and this will cut DF in the Point sought V.

But if the diverging Rays make an oblique Cone, whose Base is in the Surface itself that divided the Mediums, which obtains, when the Rays are intercepted in the Surface, and there only go through a less, circular Hole. The Point sought is in the mutual Section of the Lines BF and QC, all which is demonstrated in the following Scholium.

2905.

SCHOLIUM.

The Demonstrations concerning the Refraction of oblique Rays.

WE said that the neighbouring Rays AB, Ab, refracted along BI, bi, would meet at F, if continued downwards; we must now demonstrate that the Point F was well determin'd *. 2906. Pl. 91. F. 7. * 2898.

With the Center F, at the Distances FD, FB, are describ'd the Arches Dr, Bg; because these are small, they may be looked upon as right Lines perpendicular to Fb. In the same Manner the Arch Bo, describ'd with the Center A, at the Distance AB, may be look'd upon as a right Line perpendicular to Ab.

The Line NH must be continued as far as M. From the Similitude of the Triangles we deduce the Proportions *; but we have the similar * 4. El. 6. Triangles DBE, EBL, DEL†, dDr, Bbg; ABE, EBH, Bbo, are † 8. El. 6. also similar; and also BAD, BHM; and lastly FBg, FDr.

From what is demonstrated concerning Refraction * it follows, * 2883.

$$AB : BD :: Ab : bd.$$

By Altern. and Invers. $Ab : AB :: bd : BD.$

By Division and Alternation, $Ab - AB = bo : bd - BD = bg + dr :: AB : BD :: BH : BM.$

By Comparison of the Triangles we have, bg, Bb, bo, and BL, EB, BH, in ordinate Proportion;

Therefore by Equality * $bg : bo :: BL : BH;$ * 22. El. 5.

But we had $bo : bg + dr :: BH : BM;$

Therefore again by Equality, $bg : bg + dr :: BL : BM;$

By Invers. and Divis. $dr : bg :: BM - BL = LM : BL.$

Therefore Dr, dr, bg, LM, BL, EL, are in perturbate Proportion;

for $Dr : dr :: BL : EL;$

And by Equality perturb. $Dr : bg :: LM : EL.*$

* 23. El. 5.

The Triangles also give $bg : Bg :: EL : LD;$

Therefore by Equality $Dr : Bg :: LM : LD :: LN : LE;$

In which same Ratio are FD, FB; because $Dr : Bg :: FD : FB.$

But in the sixth Figure we have this very Ratio; for

$$LN : LE :: CD : CE :: FD : FB;$$

and it is manifest that the Point F was well determin'd.

2907. If we conceive the Plane of the Figure to turn about the Axis CE, the Rays AB, Ab will make Cones, which will have the same Axis AE; all the Rays, which proceeding from A, pass between the said conical Surfaces, which are refracted, being continued backwards, tend through Dd, to Points as F, which all together make a Circle; which the Point F has describ'd, in the said Revolution of the Plane.

Now when the Rays proceeding from A are dispers'd a little, they may all be consider'd, as if they were of those, which are thus contain'd between the said Surfaces, whence follows what has been demonstrated above *.

* 2890.

2908.

We may conceive the Cone, which the Rays a little dispers'd make, plac'd in such Manner, that it may be beneath the Plane of the Figure, and may touch it; then the small Line at F, through which the Rays pass *, is all above the Plane; and all the Rays between D and F make a Pyramid whose Base is DdF, and Vertex the upper Point of the small Line at F.

* 2899.

* 2904. 2905.

The Triangle Drd is infinitely small in respect of FDd; therefore, instead of the said Base we may have the Triangle FDr. Now to demonstrate what was said of determining the Point, which is had for the Point of Dispersion, or Focus *, we must determine the Ratio, which is given between Dr and the small Line, which determines the Height of the Pyramid, which we shall call a.

2909.

Let us first suppose the diverging Rays to make a right Cone, whose Section, in the Surface separating the Mediums, is an Ellipse, whose greater Axis is equal to Bb, and whose less Axis is perpendicular to the Plane of the Figure, and equal to Bo.

We set aside Bb, and consider Bg, whose Magnitude that determines.

As FB is to FD, or CE to CD, so is Bg to Dr.

As DB is to DF, or DE to CD, so is Bo to a;

because the Vertex of the similar Triangles, from which the Proportion is deduc'd, is given between D and d.

2910.

If instead of the small Lines Bg, Bo, we take others which have the same Ratio as these, the last Terms of these Proportions will give us Lines, which will be to one another as dr and a.

2911.

The similar Triangles give Bg, Bb, Bo, and EL, EB, EH, in ordinate Proportion whence

by Equality $Bg : Bo :: EL : EH$.

We have also (Fig. 6.) $CE : CD :: EQ = EL : DT$.

* 2890.

and $DP : SD :: DE : CD :: BP = EH : FS$.

2912.

Therefore $DT : FS :: dr : a$ *.

2913.

* 2908.

If we conceive the Pyramid above-mention'd *, cut at V, we discover the Breadth of this Section by this Proportion:

$DF, FV :: DS, Sy :: Dr$, to the Breadth.

We have the Height by this Proportion,
 $DF, DU :: DS, Dy$ as a, to the Height.

Instead

Instead of dr and a , Quantities being put in the same Ratio of DT to FS *, we discover the fourth Term of both Proportions to be Vy ; * 2912. whence it follows, that the Section makes a Square, and that it was well determin'd in the Construction *.

If the diverging Rays make an oblique Cone, whose Base is in the Surface itself, which separates the Mediums, and the Diameter of the Circle equal to Bb , this ought to be taken for a smaller Axis of an Ellipse; that is, what was said of Bc , must be applied to Bb ; and therefore instead of EH we ought to make use of BE *; then the Point P falls on * 2911. E , and PS and EC are confus'd, as also ST and CT , and the Point V is had in the mutual Section of the Lines BF , QC , as has been shewn in N. 2905. * 2904. 2914.

C H A P. VIII.

Of the Refraction of Light, when the Mediums are separated by a spherical Surface.

WE have many Cases to be examin'd, which I shall briefly consider; I shall first shew in general what belongs to this Motion, and shall afterwards add some Things in particular. 2915.

Let Z and X be Mediums separated by a spherical Surface, whose Center is C , the first the less, the last the more refracting. Pl. 75. F. 1, 2, 3, 4.

The incident Ray, that passes through the Center, or would pass through if continued, is not turn'd out of it's way by Refraction *; * 2916. 2793. for a spherical Surface may be looked upon as consisting of innumerable small Planes, which are perpendicular to the Extremities of the Diameters. 2917.

Therefore the Angles of Incidence and Refraction are those, which the incident, or refracted Rays, make with such Lines. 2918.

Let NM be the incident Ray; the refracted Ray is sought. Through the Center C draw CM , as also BCD , parallel to the Ray NM ; and the Point d being taken at Pleasure; we must apply the Line dm in the Angle MCd , which is to dC , as the Sine of Incidence to the Sine of Refraction; and the refracted Ray MD , or Md , will be parallel to md . 2919.

MC makes an Angle with CD obtuse on one Side, and acute on the other; when dm exceeds dC , that is applied in the obtuse Angle; otherwise, we make use of the acute Angle; this always happens in the Passage out of a more refracting, into a less refracting Medium. 2920.

2921. If in this Case dm be not long enough, that the Application may be made, the Refraction is impossible, and the Ray does not pass into a less refracting Medium. In this Case if from the known

* 2809. Angle of Incidence, we seek the Angle of Refraction by Computation *, we find it to be greater than a right Angle ; which shews the Refraction to be impossible.

2922. We made md , dC proportional to the Sines of the Angles of Incidence and Refraction, which are as MD , DC ; whence we deduce that the refracted Ray was well determin'd, if we attend to the two Things that follow.

2923. That in every Triangle, the Sines of the Angles are proportional to
2924. the opposite Sides : And that any Angle with it's Complement to two right ones has the same Sine.

2925. Whence it follows that in the Angle MDC , the Sides MD , DC are to one another, as the Sines of the Angles MCD , or MCB , and CMD ; which Sines therefore are, as the Sines of Incidence to the Sine of Refraction ; but the Angle MCB is
* 29.El.1. equal to the Angle of Incidence * ; therefore CMD is the Angle of Refraction, or it's Complement to two right ones.

2926. When the Point D falls in the Medium, in which the incident Ray is given, as happens, when the Convexity of the Separation is given on the Side of the more refracting Medium, the refracted Ray is not the Line DM itself, but the Continuation of it.

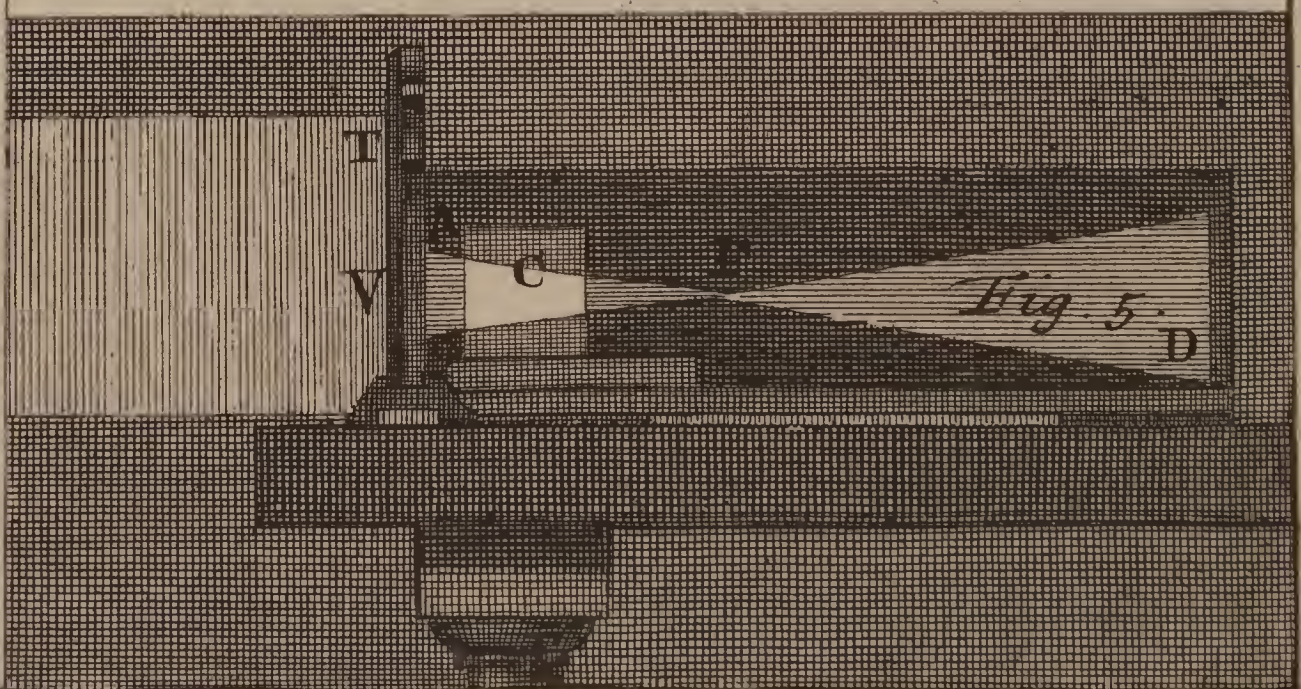
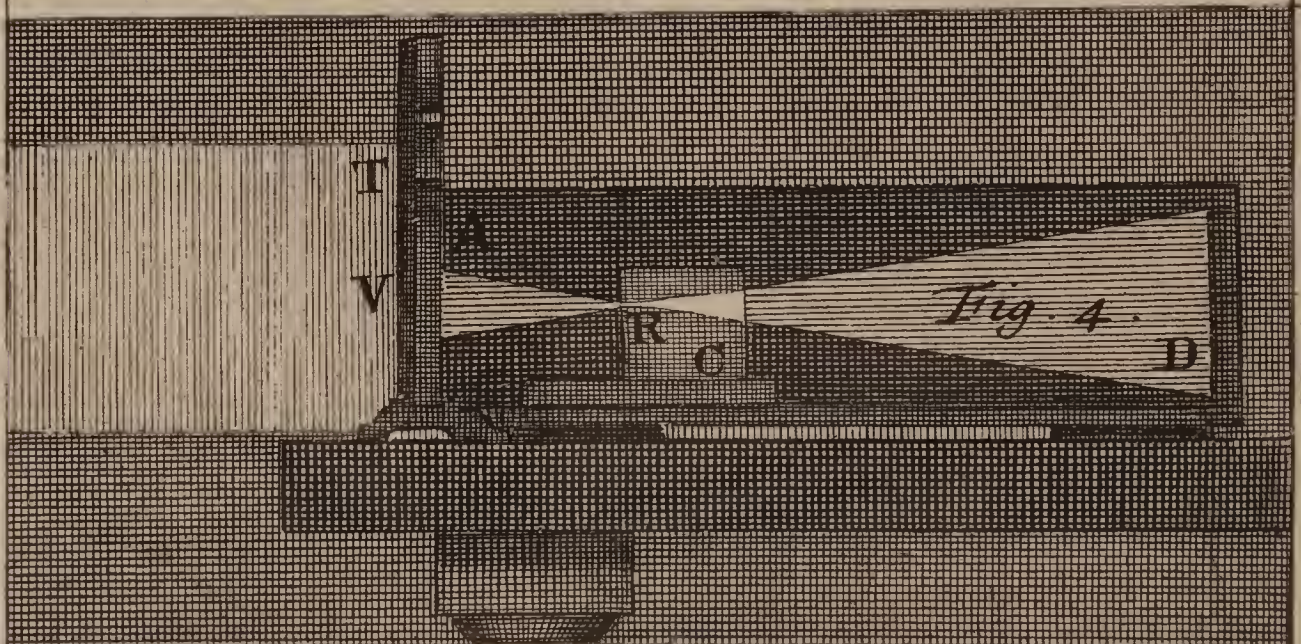
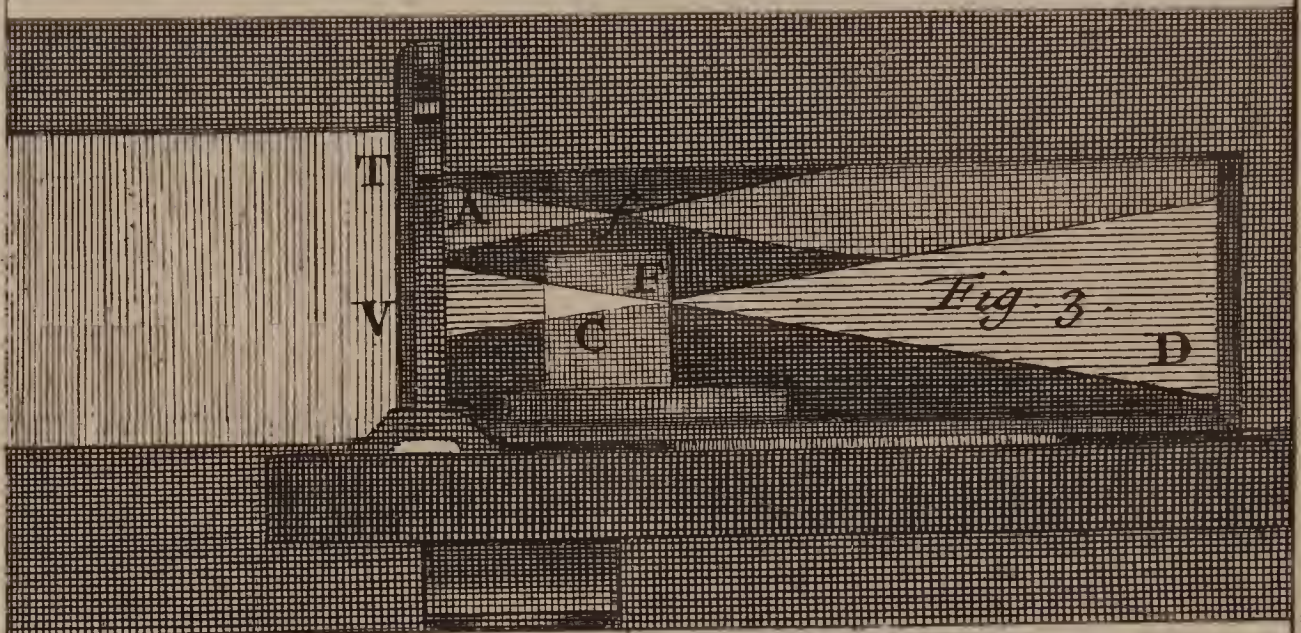
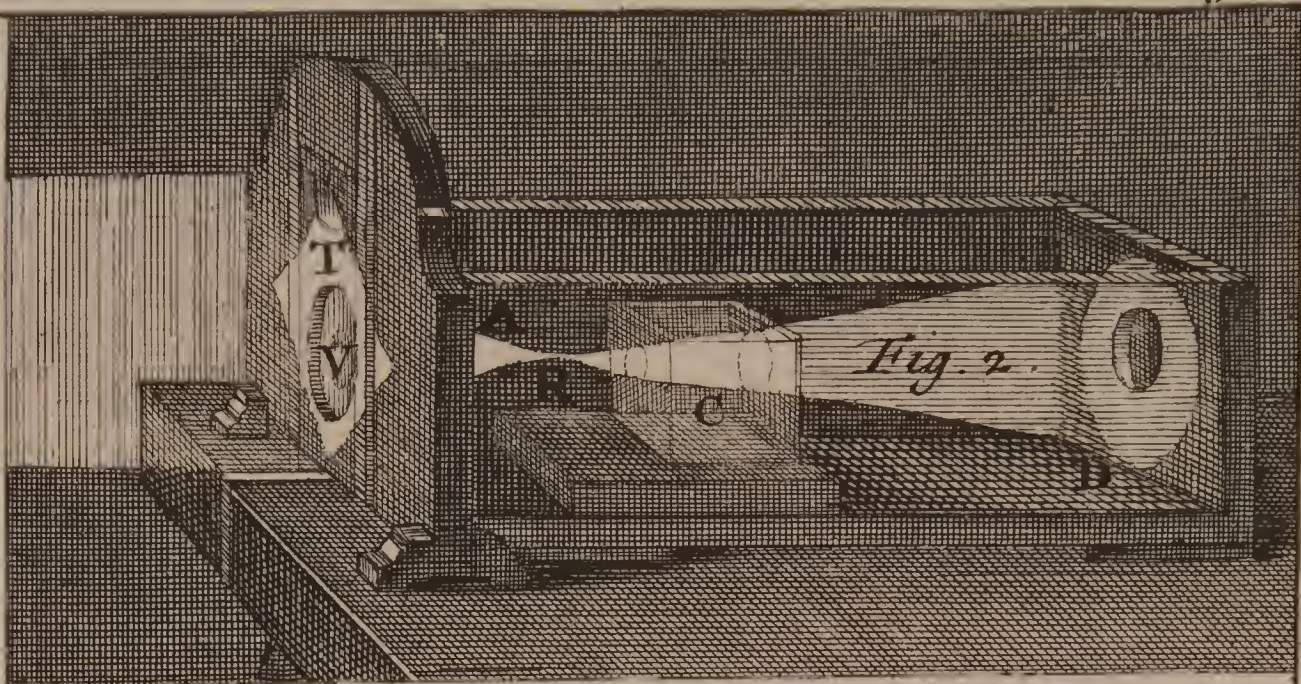
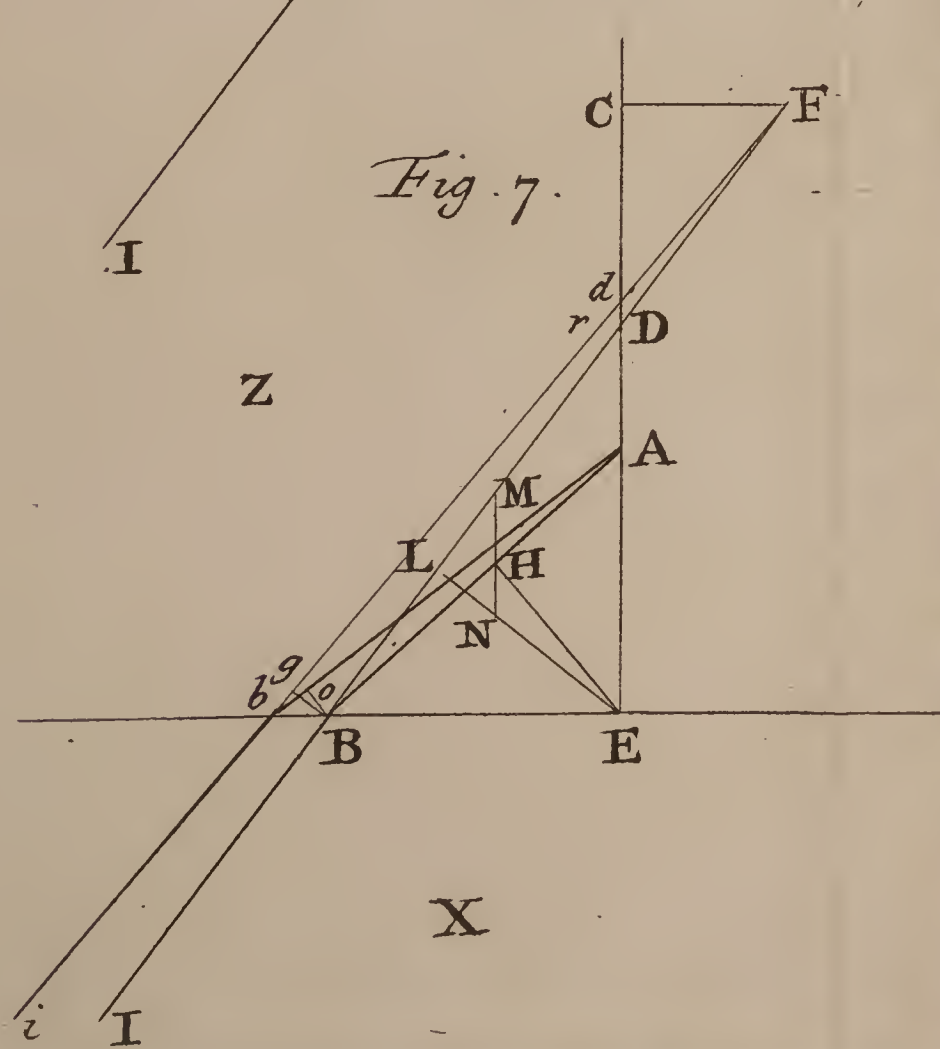
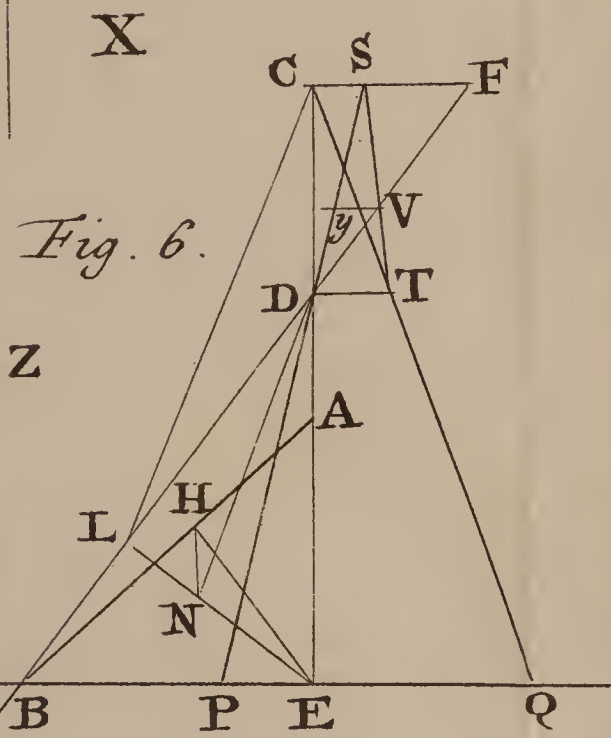
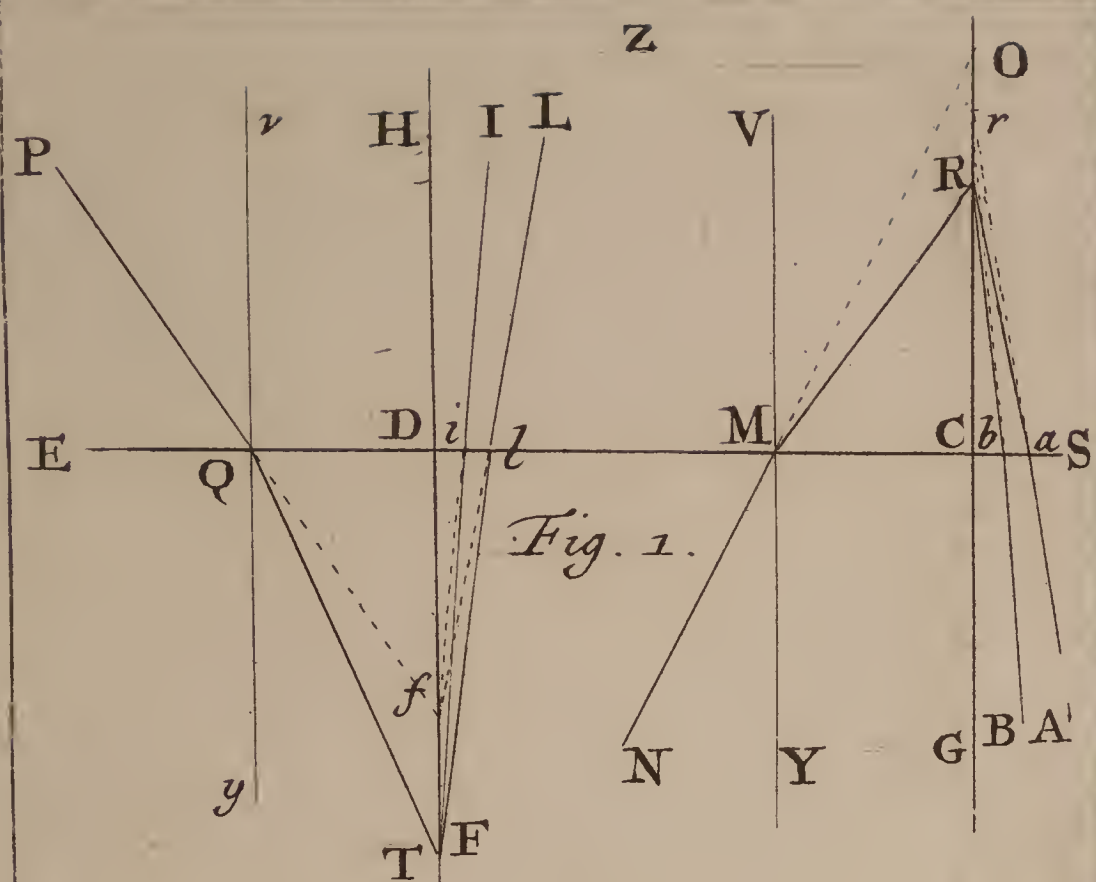
2927. Hence we deduce, how direct parallel Rays, a little dispers'd, are refracted in their Passage out of one Medium into another, if these be separated by a spherical Surface.

The Ray AB is not bent ; ab is refracted, and becomes bF , or bf ; and bF is to FC , as the Sine of Incidence to the Sine of Refraction ; but as Bb is small, BF and bF are equal to Sense. If therefore F be determin'd in such Manner, that BF be to FC in the said Ratio of the Sines of Incidence and Refraction, F will be the Focus, or Point of Dispersion, of all the refracted Rays parallel to AB , and with which this is surrounded at a small Distance. These refracted Rays are converging, when the Convexity of the Separation is given on the Side of the less refracting Medium, then they meet at F . In a contrary Disposition of the Surface they

2928. are diverging, and are mov'd, as if they proceeded from F *.

* 2926. We shall now consider in general all the different Cases of Rays
2929. that are direct and a little dispers'd.

With regard to all we must observe that the Rays which proceed from a Point, or tend towards a Point, which we affirm to belong to



Chap. 8. of Natural Philosophy.

153

to one Point, are mov'd after Refraction, to Sense, as if they also belong'd to one Point as has been demonstrated of parallel Rays; which will be seen in the first Scholium following; in which we shall demonstrate a general Rule to determine the Refraction in all Cases; which we shall be able to express more simply, if we call the Point, to which the Rays come, the Point of these Rays. But this is the Rule.

The Distance between the Point of the incident Rays and the Point of the refracted parallel Rays, proceeding from a contrary Part, is to the Distance between the same Point of the incident Rays and the Surface, that separates the Mediums, as the Distance between the said Point of the parallel Rays, proceeding from the contrary Part, and the Center of the Surface to the Distance between the Surface and the Point of the refracted Rays. 2930.

Let Z be the less refracting Medium, X the more refracting one; R the Point of the incident Rays, whether it be the Radiant of diverging Rays, or the imaginary Focus of converging ones; let E be the Focus *, or Point of Dispersion †, of parallel Rays proceeding from contrary Parts; C the Center of the Surface B V, that separates the Mediums; lastly let F be the Point of refracted Rays, that is, the Focus of converging Rays, or the Point of Dispersion of diverging ones. According to the Rule *, R E is to R V, as E C to V F; with regard to which Proportion it must be observ'd, that V F is put at the same Part with E C, when R E and R V are at the same Part of the Point R, but if R falls between E and V, let E C and V F be taken towards contrary Parts. 2931. Pl. 99. Fig. 5, 6, 7, 8. * 2927. † 2928. * 2930.

The same four Figures are of Use, in considering contrary Motion; then F is the Point of the incident Rays and R the Point of the refracted Rays; but then instead of E we ought to make use of e, the Focus of parallel, opposite Rays, and the Proportion is alter'd into this, F e is to F V, as e C is to V R. 2932.

If, neglecting the accurate Determination of Refraction, we wou'd consider all the Cases separately, we ought only to have regard to this, whether the Refraction be towards the Perpendicular, or from it, and we shall easily discover what follows. 2933.

If the Light passes out of a less refracting Medium, into a more refracting one, these being separated by a spherical Surface, whose Convexity is towards the Part of the first Medium, these Things obtain. 2934.

Parallel Rays become convergent.

EXPERIMENT 1.

2935. We join together the two Boxes D A *, and P † in such Man-
 Pl. 92. ner, that the convex Surface of the Glass V may be outwards,
 Fig. 1. this last Box is fill'd with Water. We make use of an horizontal
 * 2765. Ray, as in the Experiments of the two last Chapters.
 † 2761. The Light enters the first Box through the Hole *d*, and the pa-
 * 2801. rallel Rays make a Cylinder, which distinctly appears by Means of
 white Powder *. These Rays go through the convex Surface into
 the Water, become converging, and meet at F.
2936. *Diverging Rays, the Radiant being remov'd enough, become con-
 verging also; but the Radiant approaching, the Focus is remov'd,
 and the contrary.*

EXPERIMENT 2.

2937. All Things remaining as in the foregoing Experiment, we make
 Pl. 92. use of the Board T *, that is furnish'd with a Glass, which col-
 Fig. 2. lects the Sun's Rays at the Distance of four or five Inches: Then
 * 2772. the Rays make the Radiant Point R, and diverging, go through
 the convex Surface into the Water; they become converging, and
 meet at the Focus F; which, when it is remov'd by a removal of
 the Board T, or brought nearer, the Radiant R is agitated with a
 contrary Motion.
2938. *The radiant Point may be brought so near the Surface separating
 the Mediums, that the Focus will recede to an infinite Distance,
 that is, that the refracted Rays will become parallel.*

EXPERIMENT 3.

2939. Things being order'd as in the last Experiment, the Board T
 Pl. 92. must be mov'd gently in such Manner, that the Focus may recede,
 Fig. 3. by the approaching of the Radiant R, and the Position is easily
 discover'd, in which the refracted Rays are parallel.
2240. *If the Radiant Point R is brought nearer, the refracted Rays will
 become diverging, yet less diverging than incident Rays.*

EXPERIMENT 4.

2941. In this Experiment the Board T is at a less Distance from V,
 Pl. 92. than in the last, in other Things they agree; but the Rays are di-
 Fig. 4. verging in the Water, but less than in the Air.
2642. *If the incident rays are converging, and tend to the Center of the
 spherical Surface, they undergo no Refraction.*

Chap. 8. of Natural Philosophy.

155

*If they be directed towards another Point, as they are refracted towards the Perpendicular *, the Rays are so bent, that the Focus of these converging Rays is always given between the Center of the Surface separating the Mediums, (towards which all the Perpendiculars are directed) and the Point, towards which the incident Rays tend. That is, if the imaginary Focus of the incident Rays be at a less Distance than the Center, the refracted Rays are less converging: If this imaginary Focus be beyond the Center, the refracted Rays will be more converging.*

2943.

* 2787.2840.

The last of these Cases only is well represented in the Experiment.

EXPERIMENT 5.

This Experiment also differs from the foregoing ones only in the Position of the Board T, for if T be mov'd nearer to the Surface V, which separates the Water from the Air, the converging Rays will enter into the Water; now if this Board be so dispos'd, that the Rays may be directed to the Point, that is at a greater Distance from the Surface, than the Center of it, the refracted Rays will be more converging.

2944.

Pl.92.F.5.

Now if we suppose the Surface to be turned, and to be convex on the Side of the more refracting Medium, and the Light to pass out of a less refracting into a more refracting Medium, as in the foregoing Cases, the Phenomena are discover'd in the same Manner, by considering that the Refraction is towards the Perpendicular.

2945.

Parallel Rays become diverging.

EXPERIMENT 6.

Things being order'd as in the first Experiment the Box P is turn'd in such manner, that the Rays may go through the convex Surface, which is towards the Water, into it; the Rays will be diverging in the Water.

2946.

Pl.92.F.6.

If the Rays be diverging, and the Radiant be in the Center of the Surface, that separates the Mediums, the Rays are not bent by Refraction.

2947.

If the Radiant be at a less Distance from the Surface, the refracted Rays will be less diverging. But if the radiant Point be more remov'd from the Surface than the Center, the refracted Rays are more dispers'd than the incident Rays. Which is confirm'd by Experiment.

2948.

EXPERIMENT 7.

The Box P remaining in the Position mention'd, the rest agrees with the second Experiment *; and the diverging Rays become more diverging, whilst they go into the Water.

2949.

Pl.32.F.7.

* 2937.

2950. *If the Rays be converging, and the imaginary Focus be in the more refracting Medium at a small Distance from the Surface separating the Mediums, the refracted Rays converge also, but less than the incident Rays.*

2951. *If the imaginary Focus of the incident Rays recedes more, that is, if the said Rays converge less, the refracted Rays will also converge less, till, by the receding of the imaginary Focus, the refracted Rays are parallel.*

2952. *In a greater Recess of the imaginary Focus, the refracted Rays become diverging.*

EXPERIMENT 8.

2953. *All Things being order'd, as in the last Experiment, move the Board T towards the Surface in such Manner, that the converging Rays may enter into the Water, and the imaginary Focus may be at a small Distance from the Surface, the refracted Rays become less converging, and meet at F.*

2954. *If the Board be brought nearer and nearer the Focus recedes, and the refracted Rays will become parallel.*

2955. *And these are diverging, if the Convergency of the incident Rays be yet diminish'd more.*

Fig. 10. *After the same Manner we determine, what obtains in the Passage out of a more refracting Medium into a less refracting one; and first indeed if the convex Surface be given towards the less refracting Medium.*

Parallel Rays after Refraction meet in the Focus.

2957. *The Rays that come from a radiant Point, do also meet in the Point or Focus; and as this Point is brought nearer, the Focus goes farther off, and contrariwise.*

2958. *The radiant Point may be so plac'd, that the Focus will fly off to an infinite Distance, that is, the refracted Rays will become parallel.*

2959. *If the radiant Point be brought nearer, the Rays that are refracted will diverge; but yet less than the incident Rays, if the radiant Point be more distant from the Surface than the Center.*

2960. *But if the radiant Point be between the Surface and Center, the refracted Rays will be more diverging.*

2961. *If the Rays are converging, they become more converging in every Case.*

Fig. 1.

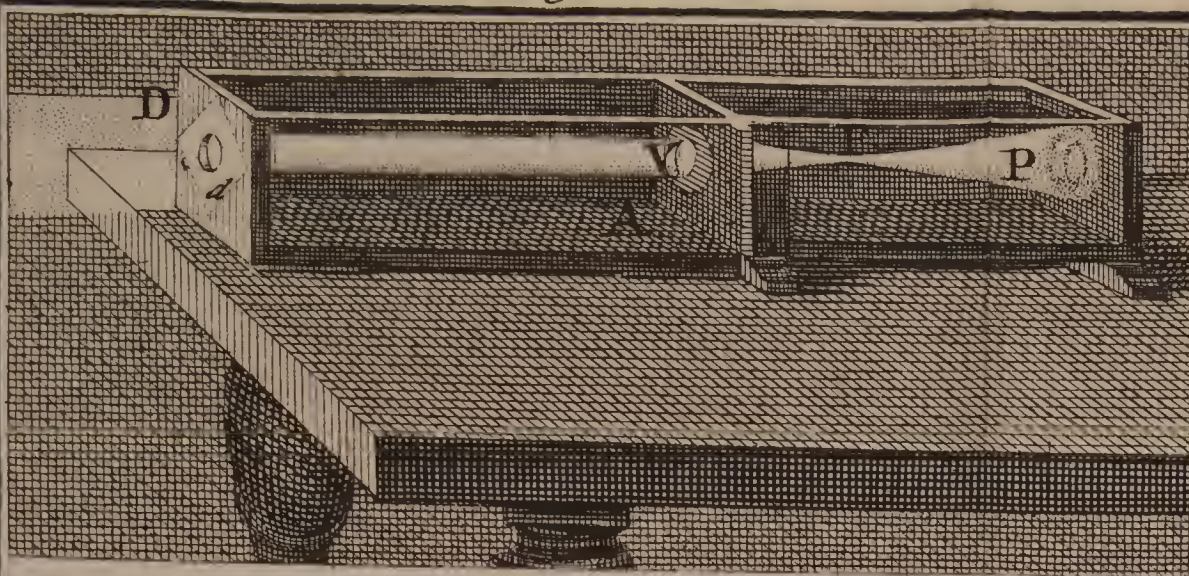


Fig. 2.

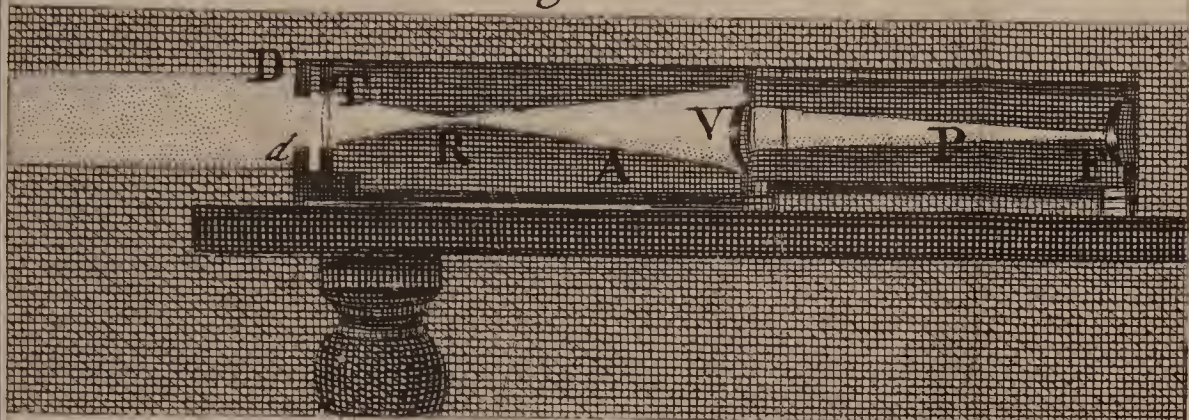


Fig. 3.

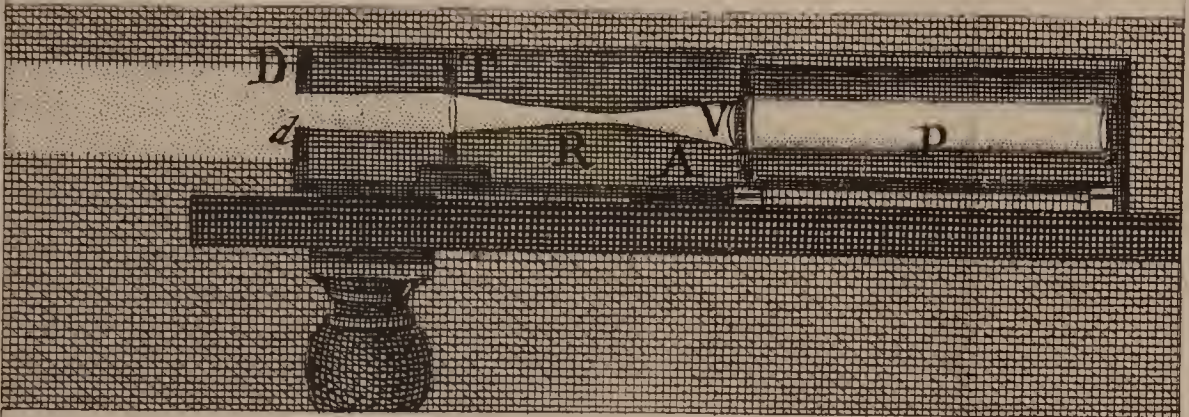


Fig. 4.

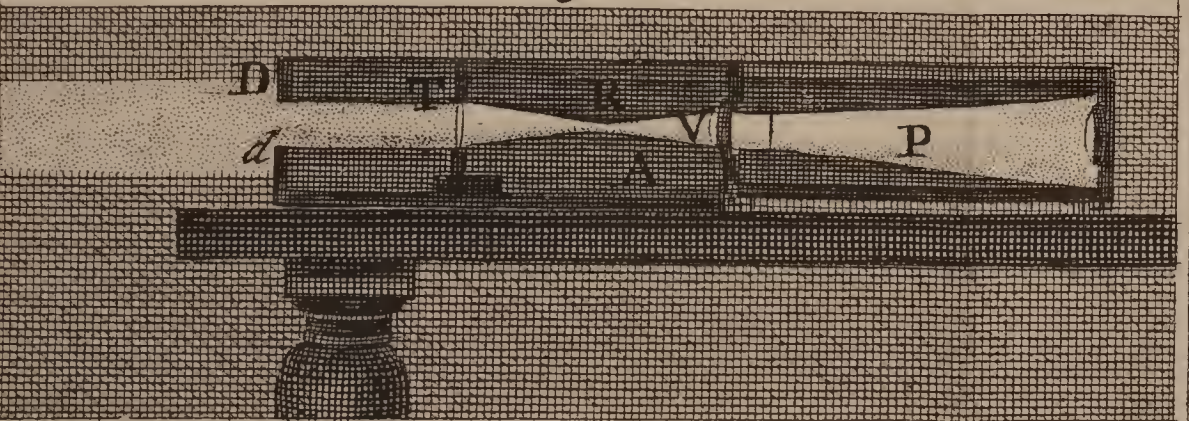


Fig. 5.

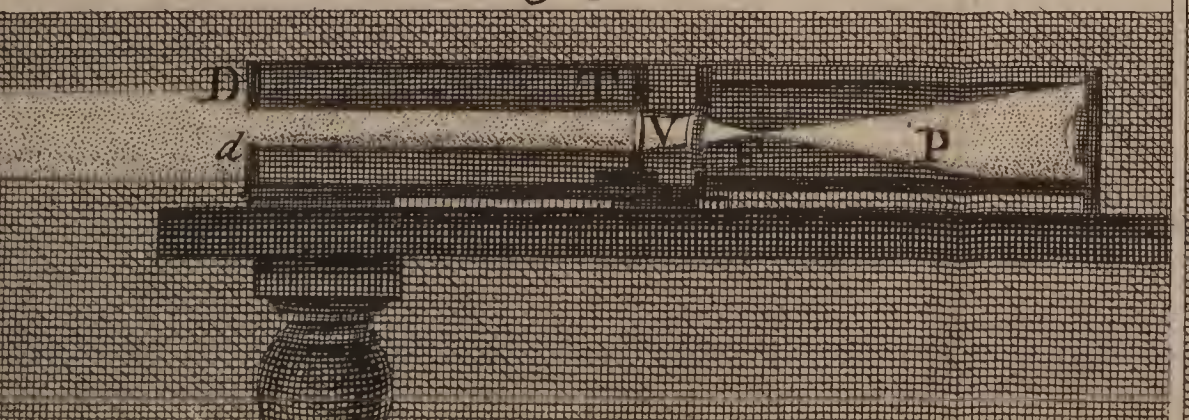


Fig. 6.



Fig. 7.

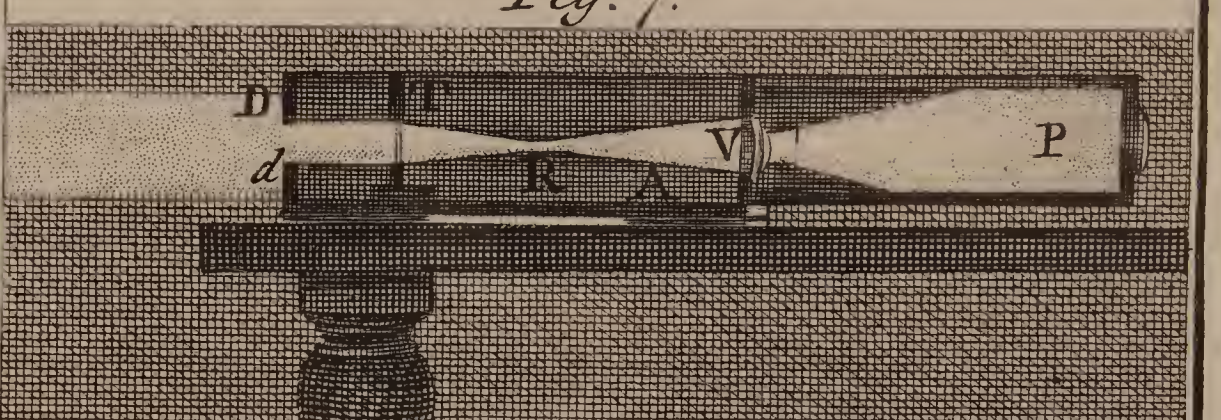


Fig. 8.



Fig. 9.

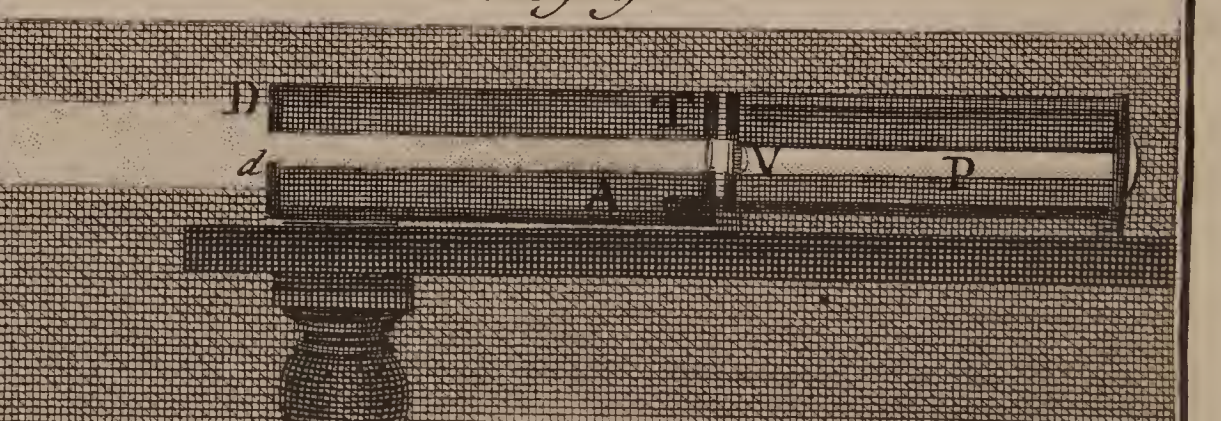
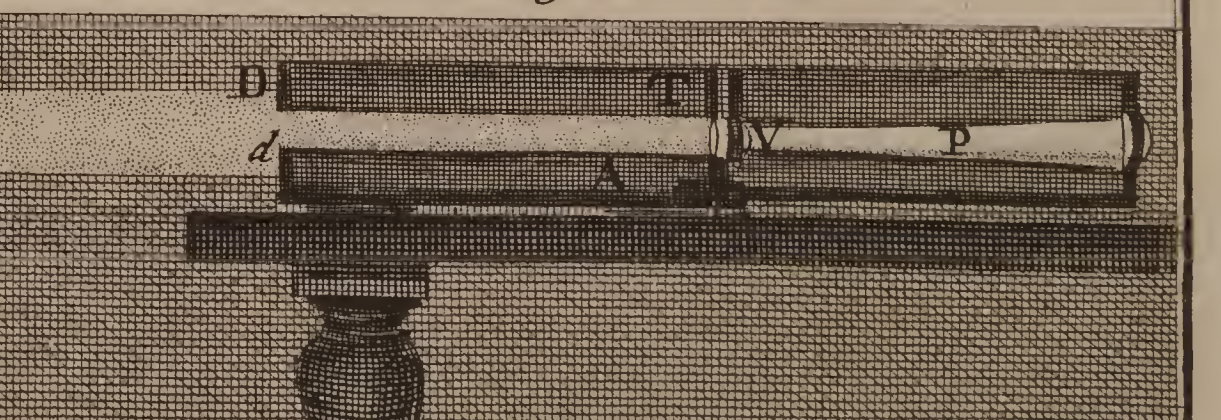


Fig. 10.



EXPERIMENT 9.

We make use of the long Box AB which is open at the Sides * ; across this, at right Angles is plac'd the smaller Box FE †, in such a Position, that the Rays, which enter the greater Box through the Hole d, and follow the Direction of it, pass perpendicularly through the Glass Plane of the smaller Box, and go out of it through the Glass V, whose Convexity is outwards. 2962. Pl.93.F.1. * 2755. † 2766.

The Box is fill'd with Water, and the Rays, which are parallel in Air, keep their Direction in the Water *, and pass into the Air through the spherical Surface, whose Center is towards the Water ; but they converge in the Air. * 2793.

EXPERIMENT 10.

All Things remaining, the Board T, that has the convex Glass *, is so plac'd, that the diverging Rays may enter into the Water, through the Surface of the Glass Plane of the Box E, then the Rays, which remain diverging in the Water †, going into Air, become converging. 2963. Pl.93.F.2. * 2772. † 2885.

If the Radiant comes nearer, the Focus will recede ; and lastly the Rays going out of the Water are parallel. 2964. Pl.93.F.3.

If the Radiant be brought still nearer, so that it be in the Surface of the Glass Plane, the diverging Rays in their Passage into Air remain diverging, but they diverge less than in Water. 2965. Pl.93.F.4.

EXPERIMENT 11.

Move the Board T towards the Box E in such Manner, that the converging Rays may go out of the Water, and they will converge more in the Air. 2966. Pl.94.F.1.

There remain to be consider'd the Rays, which go out of a more refracting Medium into a less refracting one, the concave Surface being towards the less refracting Medium. If these Rays be parallel, they become diverging by Refraction. 2967.

If they proceed from a radiant Point, they become more diverging. And they still diverge more and more, as the radiant Point is brought nearer. 2968. 2969.

Converging Rays, which tend to the Center of the spherical Surface, undergo no Alteration. 2970.

If they converge more or less, the imaginary Focus of the incident Rays will always be between the Center of the Surface separating the Mediums, and the Focus of the refracted Rays ; which can recede ad infinitum, so as to make the refracted Rays parallel. 2971.

EXPERIMENT 12.

2972. This Experiment agrees with the ninth; only the Position of
 Pl. 94. the Box F E is alter'd in such Manner, that the Rays may pass
 Fig. 2. through the Glass R; then the Rays, which are parallel in the
 Water, going into the Air diverge.

EXPERIMENT 13.

2973. If by making use of the Board T, the Rays diverge in the Wa-
 Pl. 94. ter, they go out more diverging, and as the Radiant comes nearer,
 Fig. 3. their Disperſion at the going out is increas'd.

EXPERIMENT 14.

2974. If, the Board being brought near, as in the eleventh Experi-
 Pl. 94. ment, the converging Rays fall upon the convex Surface of the
 Fig. 4. Glass R, in going into the Air they will be leſs converging.

The Board T being brought towards the Box E, the Focus F
 2975. will recede, and thus this is eaſily remov'd, that the Rays may be-
 come parallel.

2976. If then the Board be brought nearer, the Rays will diverge in
 Air.

2977. If there be many radiant Points, and Rays paſs directly from all
 of them into a more refracting Medium, through the convex ſphe-
 rical Surface on the Side of the leſs refracting Medium, the Di-
 ſtance of the Radiants being ſuppos'd ſufficiently great, every one
 of theſe will have it's Focus *; but every one of theſe is given,
 with it's Radiant, in the ſame right Line, which paſſes through
 the Center of the Sphere, a Portion of which the Surface makes.
 When all the Radiants are equally diſtant from this Surface, which
 ſeparates the Mediums, all the Foci are alſo equally remov'd from
 it on the oppoſite Side. But when all the ſaid Lines paſs through
 the ſame Point, they make two Pyramids, oppoſite at the Vertex,
 and ſimilar; wherefore all the Foci are diſpos'd among themſelves,
 as the radiant Points themſelves, but in an inverted Poſition. If
 theſe Foci fall upon a white Surface, and the extraneous Light be
 not too vivid, they will exhibit an inverſe Picture of the radiant
 Points. But it is required that the radiant Points take up a ſmall
 Space, otherwiſe the Rays from all, will not be direct together and
 a little diſpers'd for each of them.

Fig. 1.

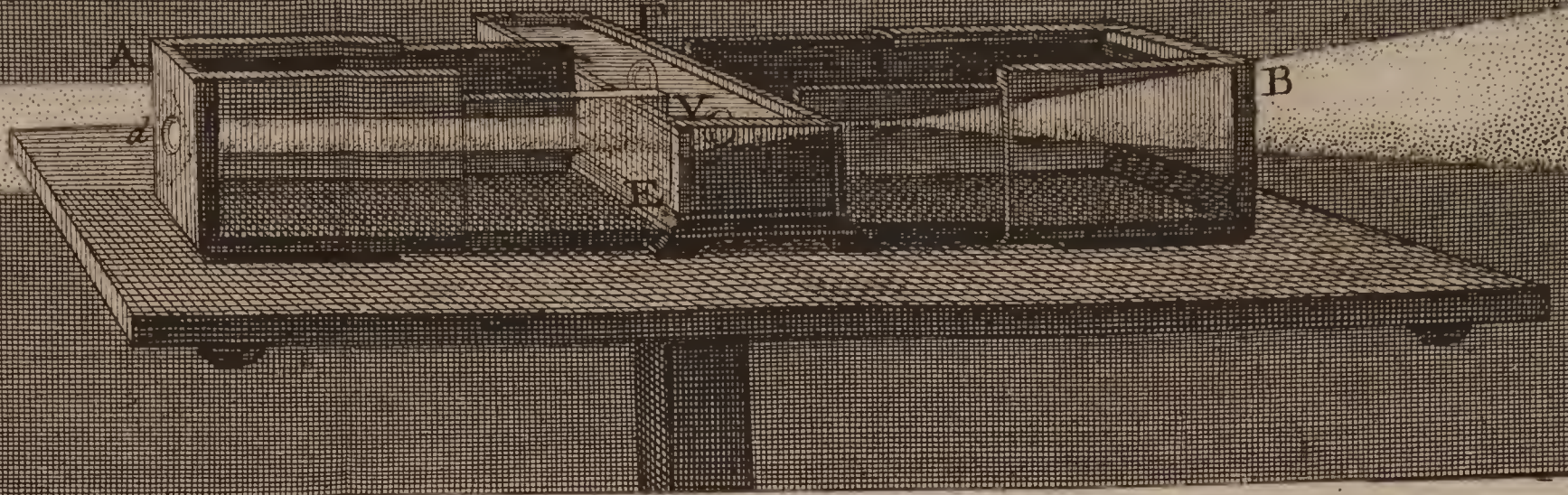


Fig. 2.

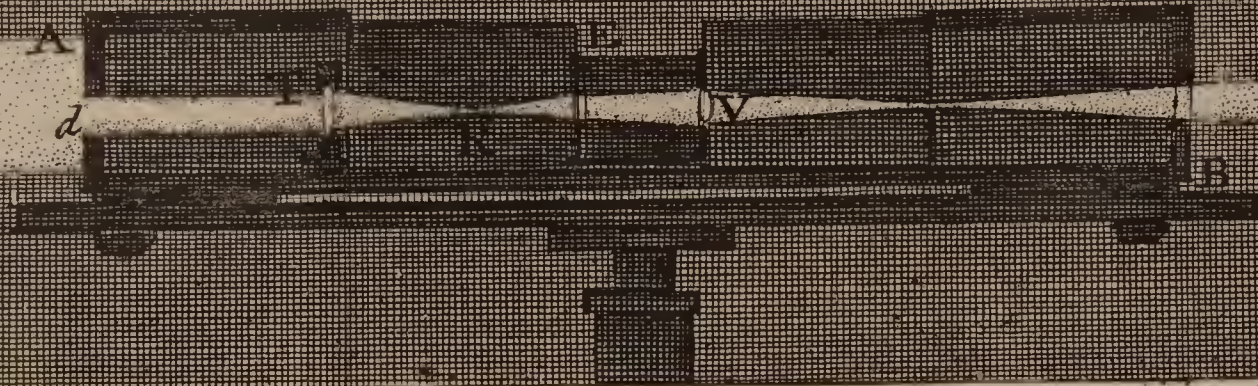


Fig. 3.

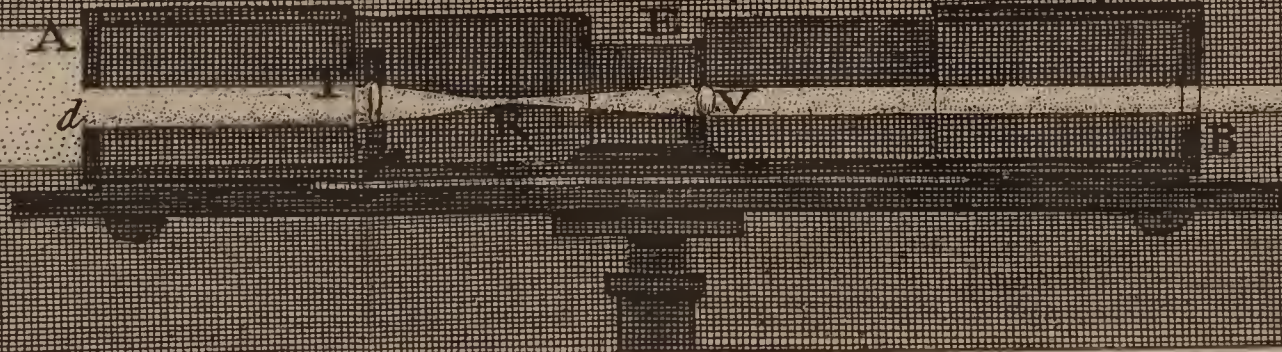


Fig. 4.

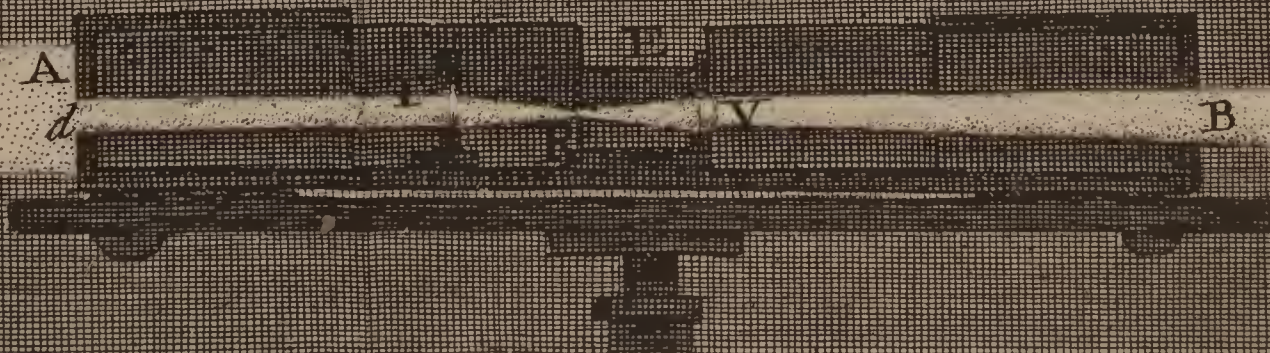




Fig. 1.

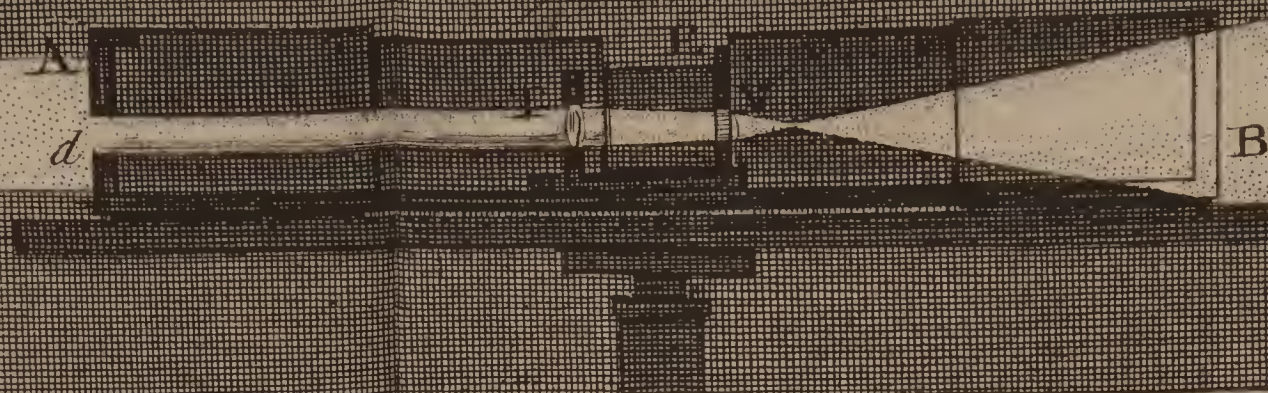


Fig. 2.

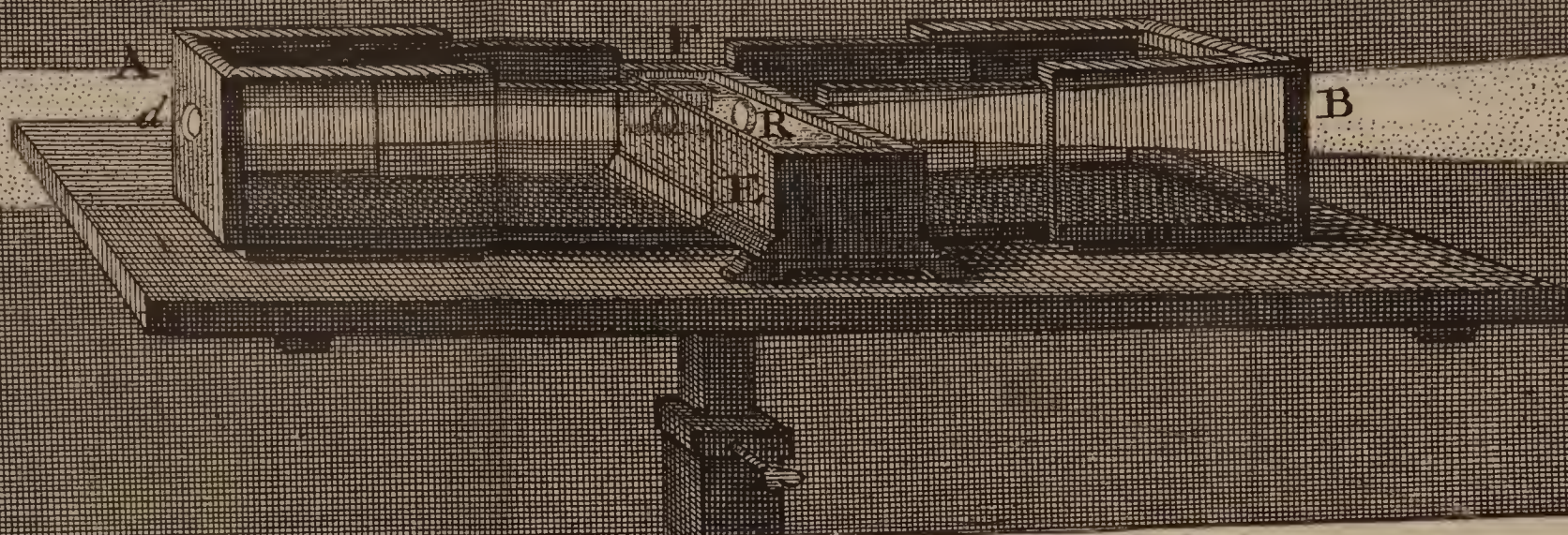


Fig. 3.

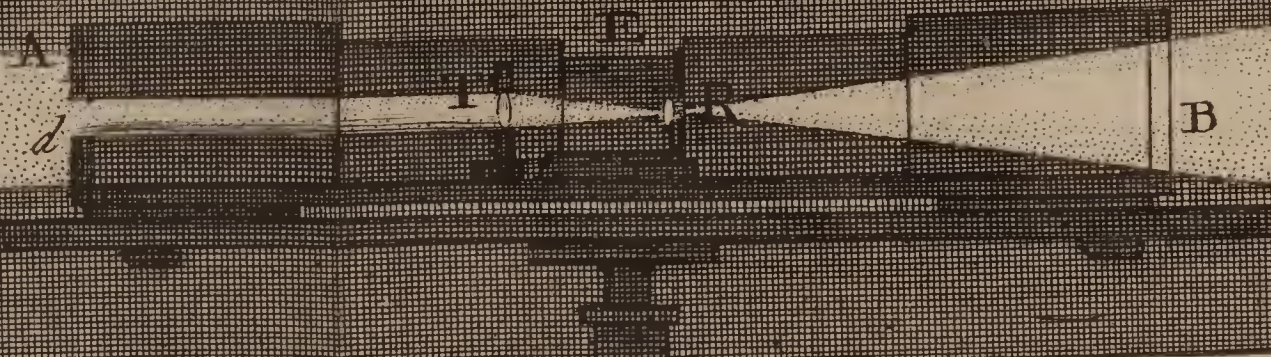
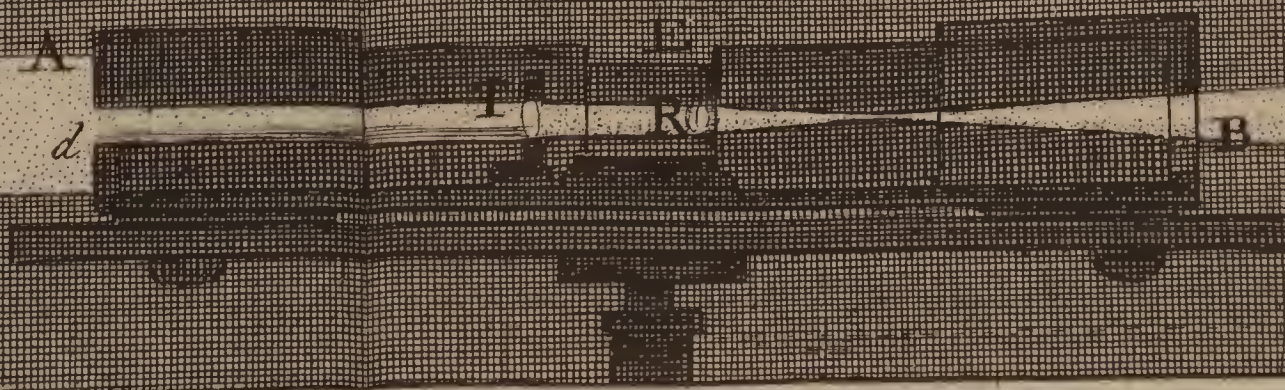


Fig. 4.



EXPERIMENT 15.

All the Points of the Surface of the Flame C, are radiant Points; 2978.
at the Distance of two or three Feet from the Candle is plac'd the Pl. 96.
Box P * in such Manner, that the Glass, whose convex Surface Fig. 1.
is outwards, may be turn'd to the Candle, and the Light, which * 2671.
enters through it into the Box, may be carried along the Box.

The Box must be put upon the small Table *, that it's Aperture * 2773.
may be rais'd as high as the Flame. The Light is intercepted by
a Paper AB, dy'd with some dark Colour, that the Light may
enter into the Box only through the Hole d, whose Diameter is
equal to half an Inch.

The Box is fill'd with Water, and by making Trial the Position
of the small Table T, which is made white *, is sought, that the * 2762.2764.
Foci of the radiant Points may be given upon the Surface of the
Table, and all may illuminate one Point; then we shall have the
Flame of the Candle distinctly painted upon this Surface, but in-
verted.

I shall now speak of oblique Rays, a little dispers'd; but I shall 2979.
only just mention what belongs to this Matter, and demonstrate it
in the following Scholiums.

Let X be the more refracting Medium, Z the less refracting 2980.
Medium; let the Ray AB pass out of one Medium into another, Pl. 96.
falling obliquely upon the spherical Surface, separating the Mediums, F. 2, 3.
and whose Center C is. Through this we draw HCD, parallel to
AB, and we determine the refracted Ray BD *; we draw CL * 2919.
perpendicular to this, to which we draw BG parallel, cutting the
Line DC at G. Through B is drawn to the Surface, separating
the Mediums, a Tangent, which meets the same Line DC at H.
The Points H and L are join'd by a Line, that cuts BG at I. If
a parallel to AB, be drawn through I, this will cut the refracted
Ray BD at F, in which Point, all the Rays parallel to AB, and
at a small Distance from it, meet with this Ray, after Refraction.

If the oblique Rays be diverging, or converging, and a little 2981.
dispers'd, we discover the Focus, or Point of Dispersion, by the
following Construction.

Let R be the Radiant Point, or imaginary Focus of the incident 2982.
Rays; RB one of the incident Rays, or a Continuation of it; Pl. 96.
BF the same Ray refracted *; and it's Continuation BL; Let EF. 4, 5.
be the Focus, or Point of Dispersion, of parallel Rays proceeding * 2919,
from contrary Parts, in the Direction FB †.

The † 2980.

The Point G is determin'd by this Proportion, as the Sine of Refraction is to the Sine of Incidence, so is E B to E G.

From the Center C, of the Surface separating the Mediums, CL, CD, are drawn perpendicular to the Lines BH, BR; and the Points D and L are join'd by a Line; and RH is drawn parallel to DL. If then it be as RE to EG, so is HB to BI, and through I be drawn IF, also parallel to DL, F will be the Point sought.

2983. When RE and EG are directed towards the same Part, HB, BF, tend also to the same Part, as in Fig. 4; if they be opposite to the first of these Lines, HB, BF, are also directed towards contrary Parts, as in Fig. 5; which also may be thus express'd: That the Point B is to F and H, as E is to G and R.

2984. We ought to refer to this Place, what was said in the foregoing
* 2899. Chapter concerning oblique Rays*; that the Demonstrations only relate to Rays in the Plane of the Figure.

2985. If the parallel Rays make a Cylinder, whose Section through the
Pl. 96. Axis is between AB, *ab*, the refracted Rays pass through the small
Fig. 2. Line, perpendicular to the Plane of the Figure at F; and afterwards pass through the small Line D*d*. If we conceive a Plane between F and D, against which the Rays run directly, these will make there a rectangular Spot, which is had for the Focus, or
* 2903. Point of Dispersion, when it is square*.

2986. The same Things obtain in diverging and converging Rays; all
Plate 96. the Rays pass through the small Line, perpendicular to the Plane of
Fig. 4, 5. the Figure at F; and in this Plane the same Rays pass through a small Portion of the Line, which wou'd pass through R and C, and in which this small Portion wou'd be determin'd by the Intersection of the Lines BF, *bF*, continued if Occasion requir'd.

But the Places where the Spots are square are determin'd by Constructions like those, which were deliver'd in the last Chapter, which I shou'd explain more distinctly, if this Determination were of any use in explaining Phenomena.

But we spoke of determining the Point F, that it might appear, that what was demonstrated in another Case*, obtains here
* 2961. also, that *there is no Focus, or Point of Dispersion of oblique, diverging, or converging Rays, how little soever they are dispers'd, if the Mediums be separated by a spherical Surface*; which follows from what was said of the Spot, or small Space, through which the Rays between F and D pass.

All Alterations in Light, spoken of in this Chapter, are the more sensible, as the Surface, separating the Mediums, is more curve, that is, a Portion of a less Sphere.

2988.

SCHOLIUM I.

A Demonstration of the Rule, deliver'd in N. 2930, concerning the Determination of the Refraction of direct Rays.

LET us suppose the Ray RB , or rB , to be refracted along BF , or along the Continuation of it Bf ; we must demonstrate that the Refraction was well determin'd, those things being supposed, which were explain'd in N. 2931. 2989. Pl. 95.. F. 5, 6, 7, 8.

The Angle of Incidence is RCB , or it's Complement to two right ones. The Angle of Refraction is CBF , or it's Complement to two Right ones. If the Ray EB be an incident Ray, Ba will be refracted *; the Angle of Incidence will be ECB , or it's Complement to two Right ones; and the Angle of Refraction aBC ; or it's Complement to two Right ones. All those Angles (or at least their Complements, which are then to be used) are small, and therefore they are as their Sines; therefore, as there is a constant Ratio between the Sines of Incidence and Refraction, in this Case also, that is, *when the Angles are small, there is given that same constant Ratio of Refraction between the Difference of the Angles of Incidence and the Difference of the Angles of Refraction* *; that is, there is this Ratio between the Angles RBE , or rBE , and aBF , or $aBf = BFV$ †, as also between the Sines of them; which therefore are as EC to EB *. But these Sines are in a Ratio compounded of the Sine of the Angle RBE to the Sine of the Angle BRV , and the Ratio of the Sine of this last to the Sine of the Angle BFV . * 16.17. El. 5. † 29. El. 1. * 2919.

The first Ratio is that which is between RE and EB *. The second Ratio is between FB and RB , or VF and RV , by reason of the small Arch BD : therefore

$$EC : EB :: RE \times VF : EB \times RV.$$

$$EB \times RE \times FV = EC \times EB \times RV, \text{ or } RE \times FV = EC \times RV.$$

And $RE : EC :: RV : VF$. Which was to be demonstrated.

SCHOLIUM II.

The Demonstration concerning the Refraction of parallel oblique Rays, explain'd in N. 2980.

LET AB , ab , be parallel Rays; their refracted Rays BD , bd ; we also suppose what else was mention'd in N. 2980. 2990. Pl. 96. F. 2.

From the Refraction it follows, $bd : dC :: BD : DC$ *;

By Altern. and Divif. and by Altern. again, $dm \perp ab : Dd :: BD : DC$.

The Triangles Ddm and DBG are similar; and

$$Dd :: dm : DG : BD.$$

Therefore by equal Perturb. $dm + cb : dm :: DG : DC$;
 By Divif. $eb : dm :: DG - DC = CG : DC$.
 2991. But the Point F is fought, in which is given the Interfection of the Rays BD, bd .

By Reason of the similar Triangles BFe, DFm,
 2992. $Be : Dm :: BF : FD$.

The Ratio between Be and Dm is made up of the three Ratios of Be to eb, eb to dm, and lastly dm to Dm; which three Ratios we determine. GN being drawn parallel to BD, the Triangles B eb and BGN are similar, and

$Be : eb :: BG : GN$.
 * 2991. $eb : dm :: CG : DC$ * : $BL : LD$; by reason of the Parallels BG, LC.

$dm : Dm :: DB : BG$; by reason of the similar Triangles D dm, BDG.

Therefore Be is to Dm, as the Product of the Antecedents $BG \times BL \times DB$, to the Product of the Consequents $GN \times LD \times BG$, in which Ratio also BF is to FD *.

But $GN \times LD = BD \times GO$; for, by reason of the Parallels DB, GN,
 $BD : GN :: DL : GO$.

Therefore $BF : FD :: BG \times BL \times DB : BD \times GO \times BG :: BL : GO$; in which Ratio also is BI to IG, by reason of the similar Triangles BLI, IGO.

Therefore a Line drawn through I parallel to GD determines the Point F; for then $BF : FD :: BI : IG$.

2993. If we conceive the Plane of the Figure to turn about the fixed Line DCH, the Rays AB, ab , turn about in such manner, as to make Cylinders, which have the common Axis DH; all the Rays parallel to this Axis, which are contain'd between the Surfaces of these Cylinders, make by their mutual Intersections a Circle, which the Point F describes, in the said Revolution. The Rays a little dispersed, which we spoke of in N. 2980, are contain'd between the said Surfaces of the Cylinders; therefore these, by mutual Intersections, make a small Portion of the said Circle; that is, they pass through the small Line, perpendicular to the Plane of the Figure at F, as has been said *.

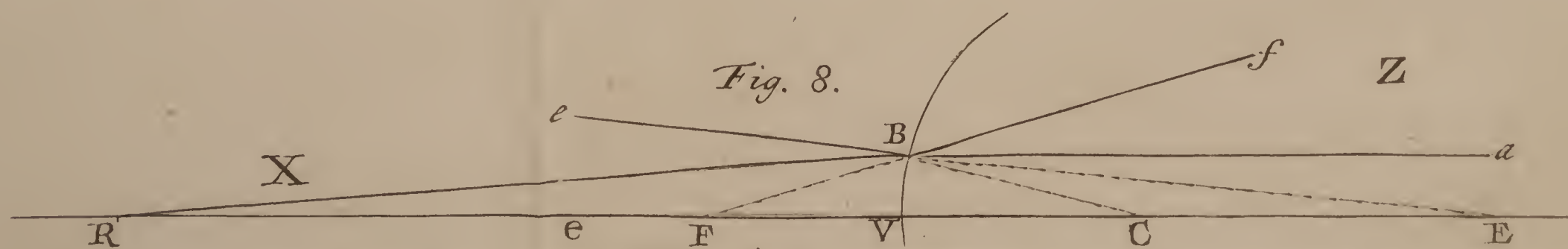
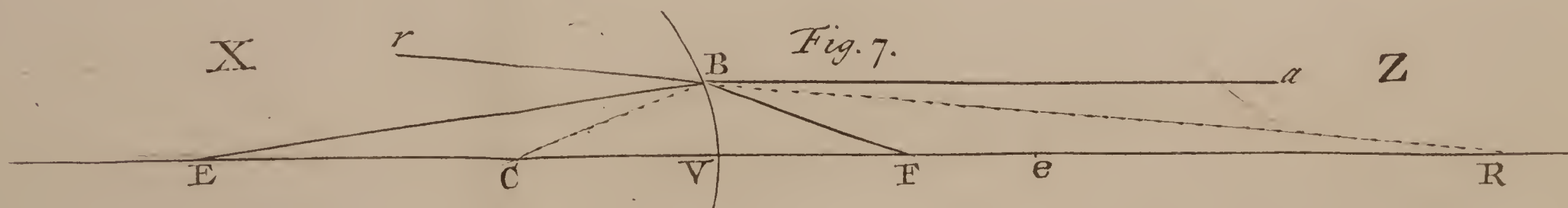
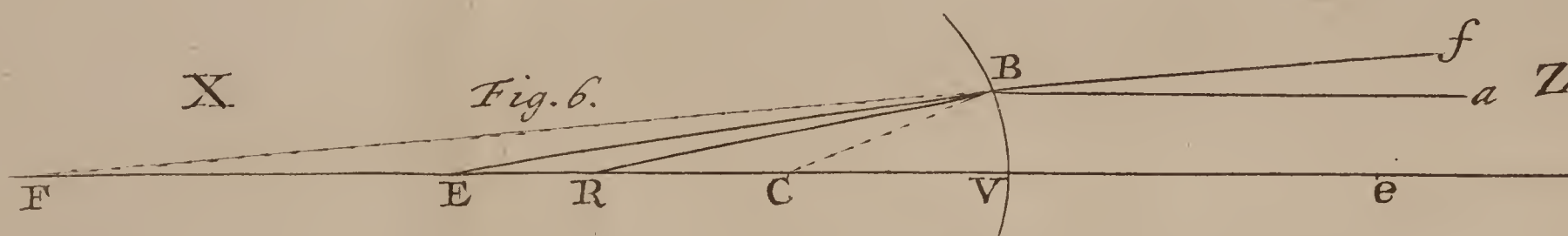
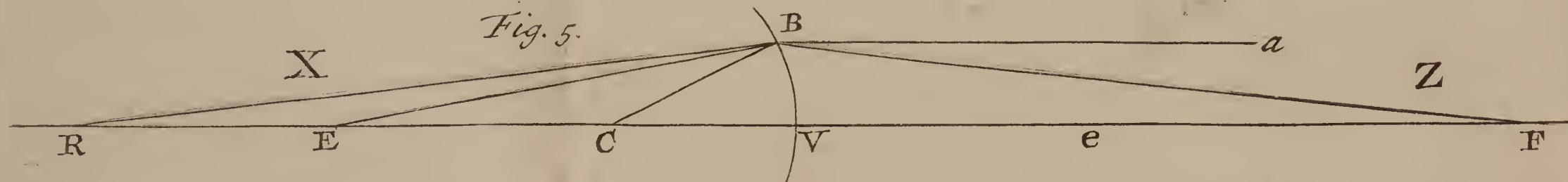
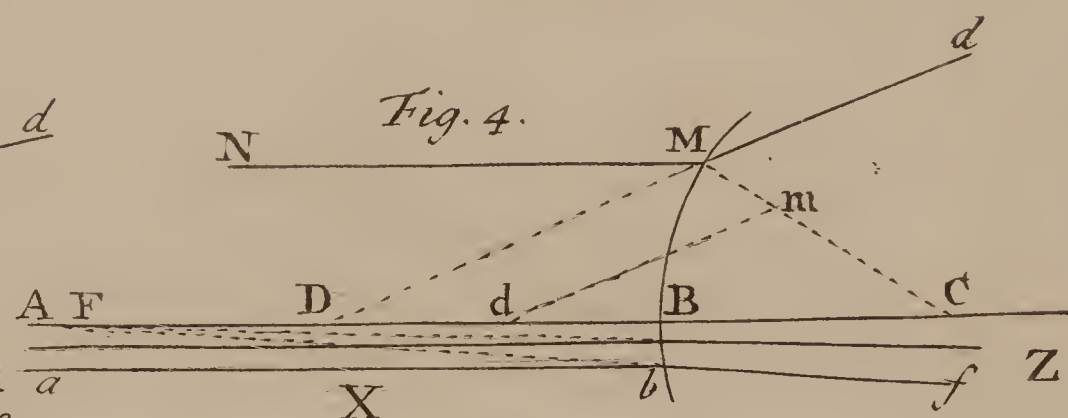
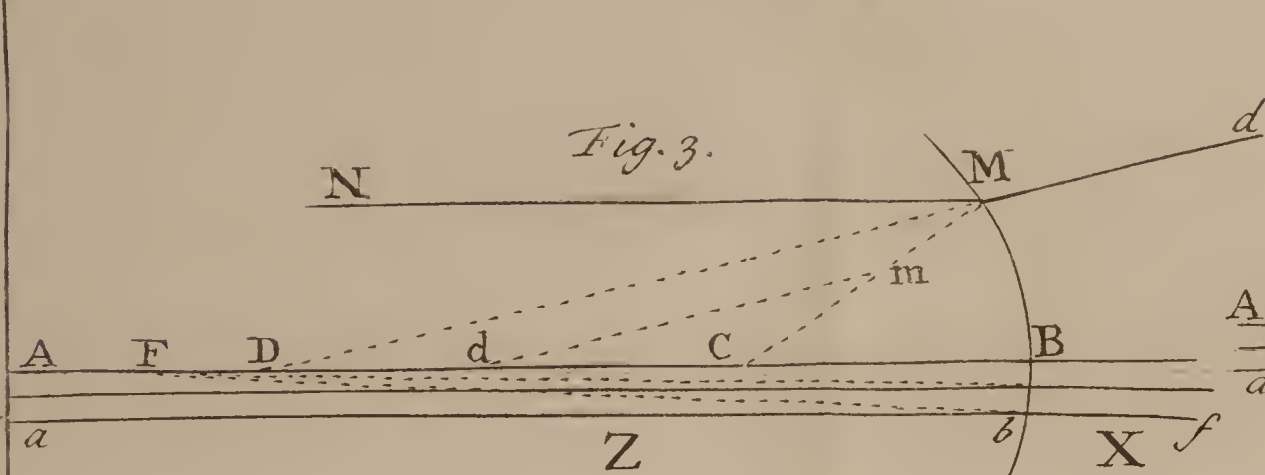
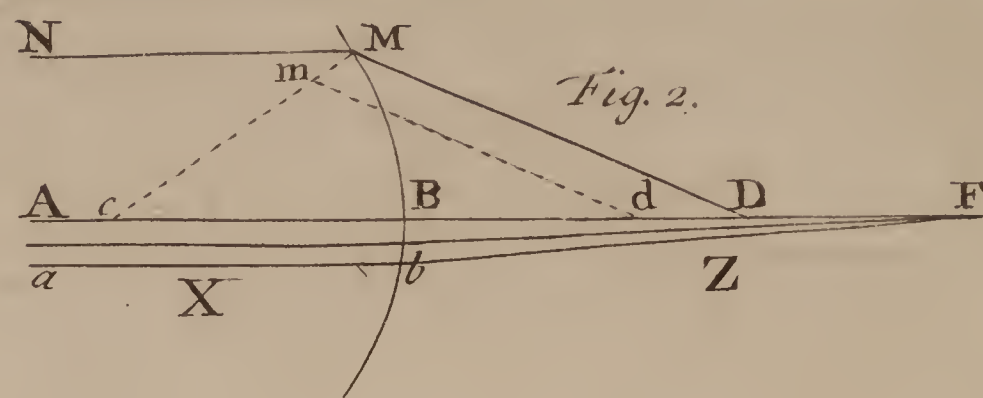
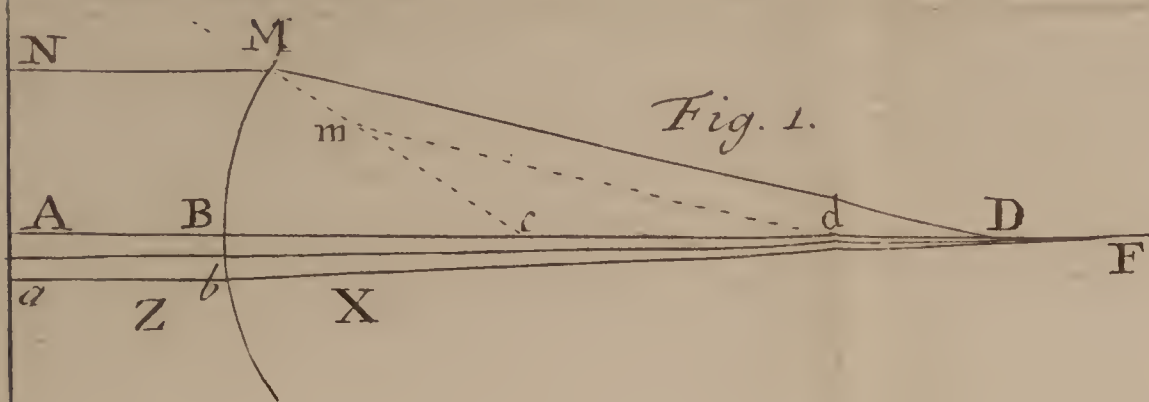
* 2985.

SCHOLIUM III.

Of the Refraction of oblique Rays, diverging, or converging, mention'd in N. 2982.

2994. Pl. 96. F. 4. **W**HAT has been explain'd in N. 2982. being supposed, we conceive the Ray Rb which is refracted along bF, meeting with the refracted Ray BF at F; we must demonstrate that the Point F was well determined.

With



With the Center R, through B, is describ'd the Arch Bm ; with the Center F, through b , is describ'd the Arch bn ; with the Center B, through the Points L, D, and E, are describ'd the Arches Ll , Dd , Ee .

The Triangles CBL , Bbn , are similar; for they are rectangular, and moreover the Angles bBn and BCl are equal; because CBL is the complement of each to a right Angle; which follows with regard to BCL from the Property of Triangles*; and with regard to bBn from this, * 32. El. 1. that the three Angles bBn , bBC , CBL , are equal to two right ones†, † 13. El. 1. and the middle one of these is a right one.

After the same manner we prove that the right-angled Triangles Bbm , BCD , whose Angles bBm , CBD are equal, are similar; because mBC is the Complement of each to a Right Angle. Therefore,

$$bn : Bb :: BL, BC.$$

$$Bb : Bm :: BC, BD;$$

And by Equality, $bn, Bm :: BL, BD :: BH, BR.$

2995.

But the Ratio of bn to Bm , is made up of the Ratios of bn to Ll , Ll to Dd , Dd to Ee , Ee to Bm .

We find all the Ratios,

2996.

By Reason of the similar Triangles Fba , BLl ,

$$bn, Ll :: FB, BL :: IB, BD.$$

For the incident Ray RB , and the refracted one BF , the Sine of Refraction is CL , and the Sine of Incidence CD ; for aB and Be , the same Sines are Cl , Cd ; therefore, by reason of the constant Ratio between these Sines*,

* 2809.

$$Ll, Dd :: CL, CD† :: BE, EG.$$

† 19. El. 5.

By Reason of the similar Triangles BDd , BEe and REe , RBm ,

$$Dd, Ee :: BD, BE;$$

$$Ee, Bm :: RE, RB.$$

Therefore the Ratio of bn to Bm , that is, of BH to BR *, is made up of these four Ratios, of IB to BD , BE to EG , BD to BE , and RE to RB . * 2995.

The Ratio compounded of the Ratios of IB to BD , BD to BE , BE to EG , is that which is between IB and EG ; which therefore only must be join'd with the Ratio of RE to RB ; and we have

$$RE \times IB, RB \times EG :: BH, BR :: BH \times BI, BR \times BI*.$$

* 1. El. 6.

The Antecedents of the first and last of these Ratios being divided by IB , and the Consequents by BR , there is given

$$RE, EG :: BH, BI.$$

Whence it appears that in the Construction N. 2982, the Point I, and therefore F, was well determin'd.

If, in order to make appear, what was explain'd in N. 2986, we would apply to these Cases, what was demonstrated in Numbers 2907 and 2993, we ought to conceive the Plane of the Figure to revolve about the fix'd Line RC , and then, what was said in these Numbers of the Rays AB , Ab , will be to be applied to the Rays RB , Rb .

2997.

C H A P. IX.

Of the Motion of Light through a more refracting Medium. Where we shall speak of the Properties of Lenses.

2998. * 2830. **T**HE use of Glasses is common; Glass is denser than Air, and more refracting according to the Ratio of the Density *; and the Rays coming out of the Air into Glass, pass though it into the Air again. Light undergoes different Changes in it's Passage through Glasses, according to the various Surfaces that terminate them. In order to determine which, the Glasses or any Mediums encompass'd with a less refracting Medium, terminated with different Surfaces, must be examin'd. *There are six Classes of Glasses arising from the sole Consideration of plane and spherical Surfaces.*

2999. 1. The Medium may be plane on both Sides. 2. It may be plane on one Side and convex on the other. 3. It may be convex on both Sides. 4. It may be plane on one Side, and concave on the other. 5. It may be concave on both Sides. 6. It may be concave on one Side, and convex on the other.

DEFINITION I.

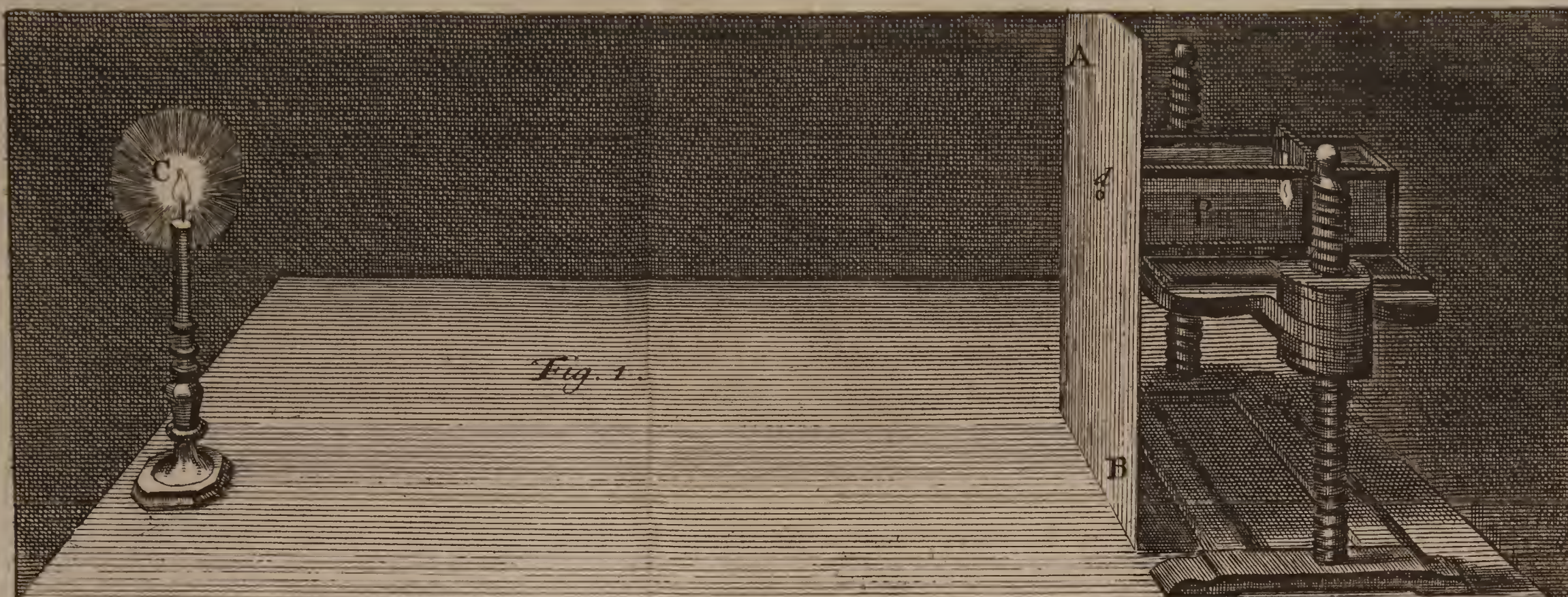
3000. *If a Glass be us'd, and it be not very thick, such a Glass as is mention'd in the five last Classes, is call'd a Glass Lense.*

3001. In the second and third Case, a Lense is said to be convex; and if these two Cases are to be distinguish'd, in the second it is call'd a Plano-convex Lense. And so in the fourth Case it is said to be Plano-concave; though both these Cases and the fifth are generally reckon'd as concave Lenses. But a concave convex Lense, is reckon'd amongst concave or convex Lenses, according as the one or the other Surface predominates, in which last Case the Lens is call'd a Meniscus. But that Surface is said to predominate which is most curve, that is, which is a Portion of a less Sphere.

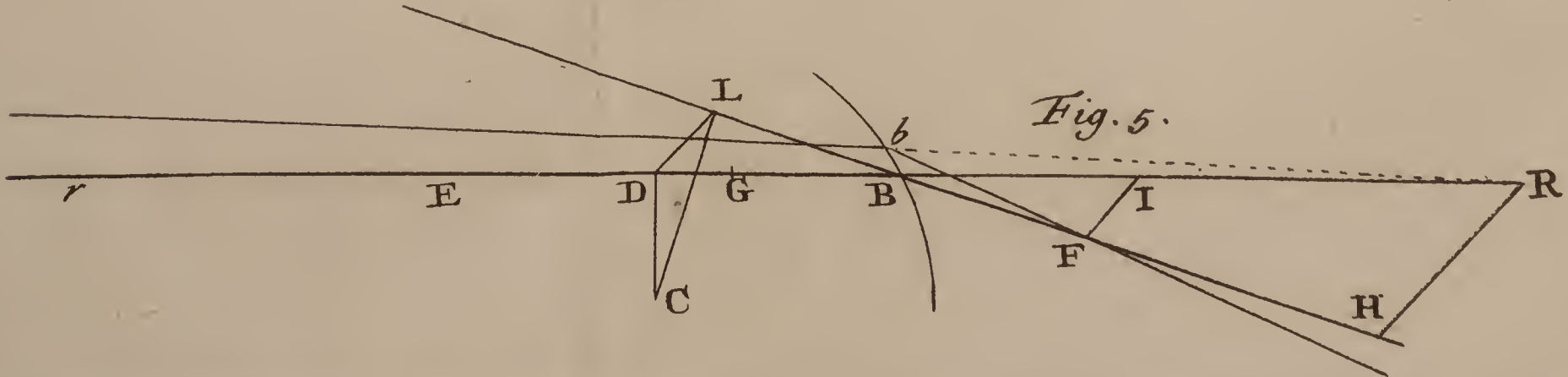
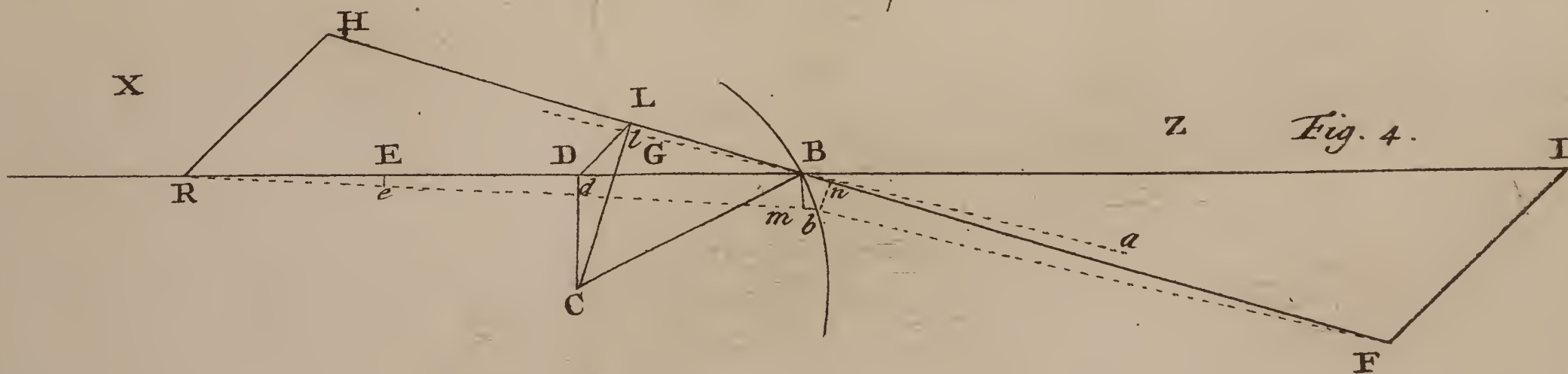
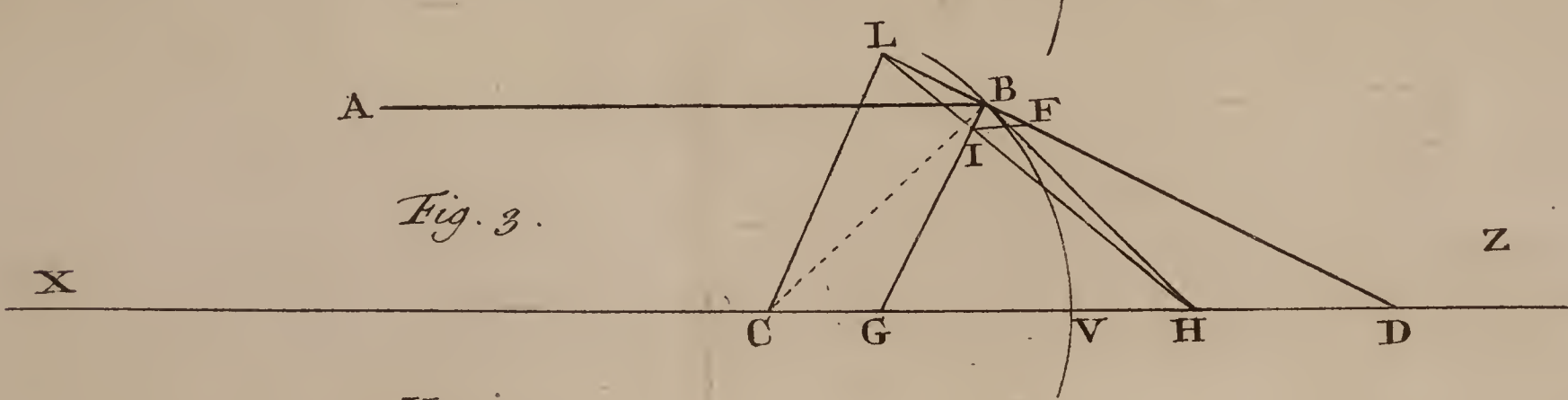
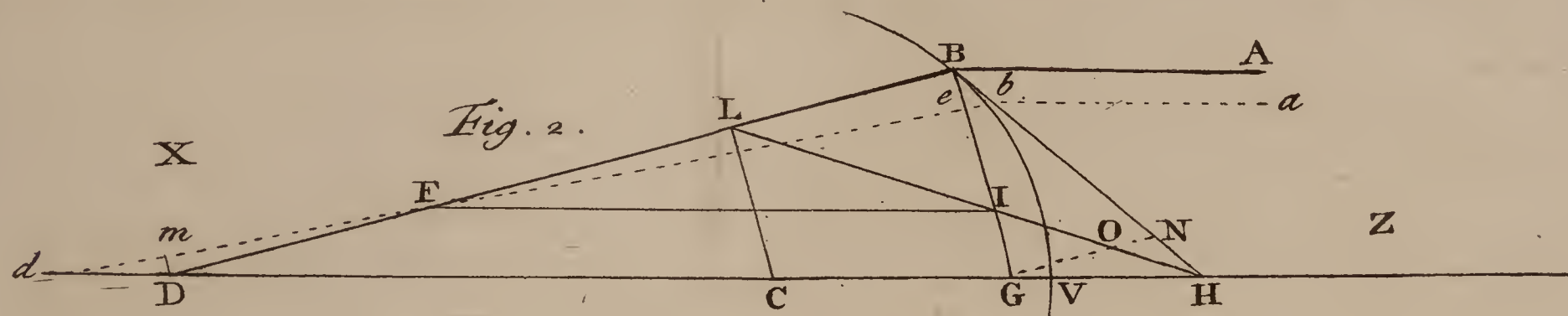
DEFINITION 2.

3002. *In any Lense or Medium terminated, as has been already said, the right Line which is perpendicular to both the Surfaces is call'd the Axis.*

When



96



A. M. M. M.

When both these Surfaces are spherical, the Axis passes through both their Centers ; but if one of them be a Plane, it falls perpendicular upon that, and goes through the Center of the other. 3003.

Regular Lenses are orbicular, and the Axis passes through the Center of the Lense, in which Case it is said to be well center'd. 3004.

In the Passage of Light through a Medium, terminated by two plane Surfaces, *the Direction of the Rays is not chang'd* *, which is the Case in plane Glasses. * 2792. 3005.

In demonstrating what relates to the Passage of Light through Lenses, we shall only consider Rays a little dispers'd, as before, and indeed principally those that are direct. But those are such, among which there is one, that coincides with the Axis of the Lense *. * 2878 3002. 3006.

It is the Nature of all Sorts of convex Lenses, that the Rays in their Passage through them are bent towards one another ; so much the more as the Convexity is greater : But of concave ones, that the Rays are deflected from one another, according as the Concavity is greater. 3007. 3008.

For the Direction of the Rays through a plane Glass is not alter'd * ; but upon inflecting one or both the Surfaces, the Rays * will have another Direction : They are more bent towards the Axis of the Lense, because of the Convexity of the Surface of the Glass ; and by making the Surface concave, they are deflected from the Axis ; as is evident in every Case, by comparing the Inflection in the plane Surface, perpendicular to the Axis of the Glass, with the Inflection in the spherical Surface. And the Difference of their Inflections, that is, the Change of the Direction of the Rays, increases with the Distance from the Axis. Whence we deduce the following Properties of Lenses. 3009. 3005.

That *parallel Rays in passing through a convex Lense, meet in the Focus.* 3010.

That *diverging Rays either diverge less, or run parallel, or else converge ; in which Case as the Radiant Point goes farther off, the Focus comes nearer, and contrariwise : And this is the Case when the Radiant Point is farther distant from the Lense than the Focus of parallel Rays.* 3011.

Lastly, That *converging Rays converge more when the Light emerges out of the Lense.* 3012.

EXPERIMENT I.

In this, and the following Experiments, we make use of the long Box A B *, which has been often us'd before ; the Sides of it are clos'd. We direct the Ray horizontally, as in many of the foregoing, * 2755. 3013. Pl. 97. F. 1.

foregoing Experiments ; according to the Direction of this the Box is plac'd, into which the Light enters through the Hole *d*. The parallel Rays are transmitted through the convex Lense, which is in the Board T *, they converge, and meet at R.

* 2772. In this, and the following Experiments, the Rays are made sensible, by making use of a white Powder *, as has been often said.

3014. We have already often us'd these converging Rays ; after their Intersection at R they are dispers'd, and R is the radiant Point, which also has been often made use of in the Experiments ; but we have now explain'd the Cause of this Effect in the Passage through the Lense.

EXPERIMENT 2.

3015. All Things remaining the same, we put a second Board S like Pl.97.F.1. T, which also has a convex Glass, into the Box A B ; the diverging Rays, proceeding from R, will become converging, and meet at the Focus F, if the Distance R S be great enough.

3016. If this Distance be diminish'd, the Focus F will recede ; and Pl.97.F.2. this may be remov'd in such Manner, that the Rays going out of the Lense S will be parallel.

3017. If the said Distance R S be then diminish'd more, the Rays that Pl.97.F.3. go out will diverge, but they will diverge less than incident Rays.

EXPERIMENT 3.

3018. Other Things remaining, the Board T must be mov'd towards Pl.97.F.4. the other S in such Manner, that the Rays may fall upon the Lense of this Board converging ; and when they go out they will converge more.

3019. We also deduce the Properties of concave Lenses from a general * 3008. Proposition *.

3020. *Parallel Rays become diverging by passing through a concave Lense.*

3021. *Diverging Rays diverge the more.*

3022. *Converging Rays sometimes converge the more ; if, in this Case, the converging of the incident Rays be diminish'd these may be directed, so that when they go out they will be parallel ; if then the incident Rays become still less converging, at their going out they will be dispers'd.*

Fig. 1

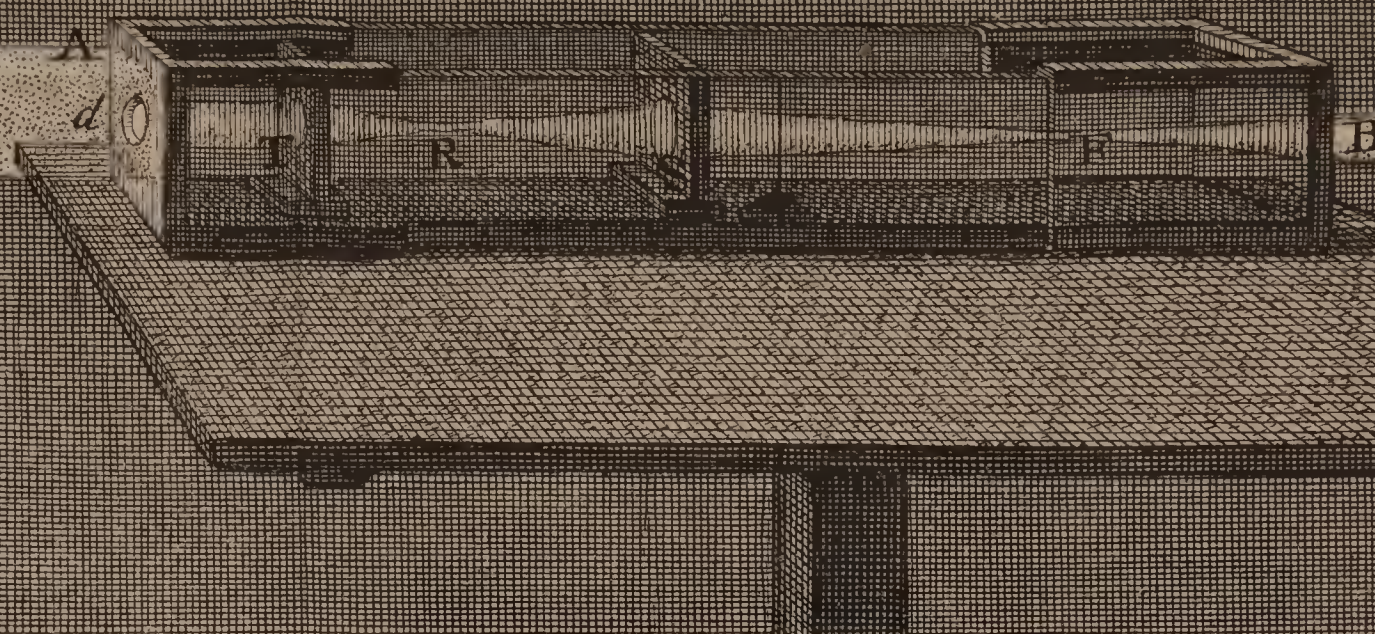


Fig. 2

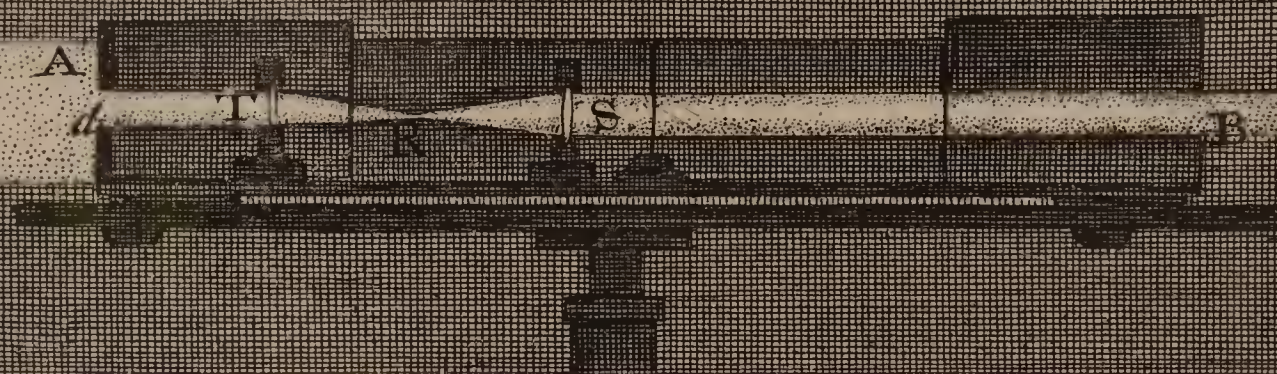


Fig. 3

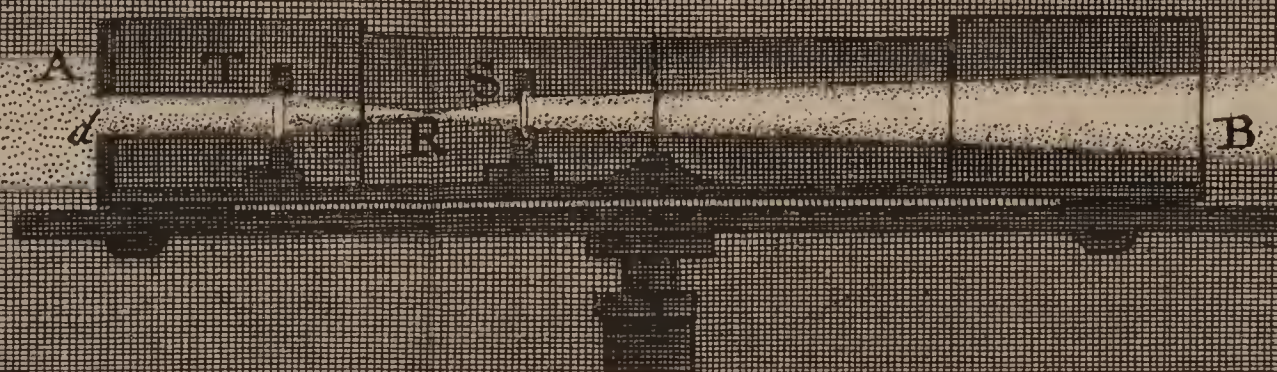
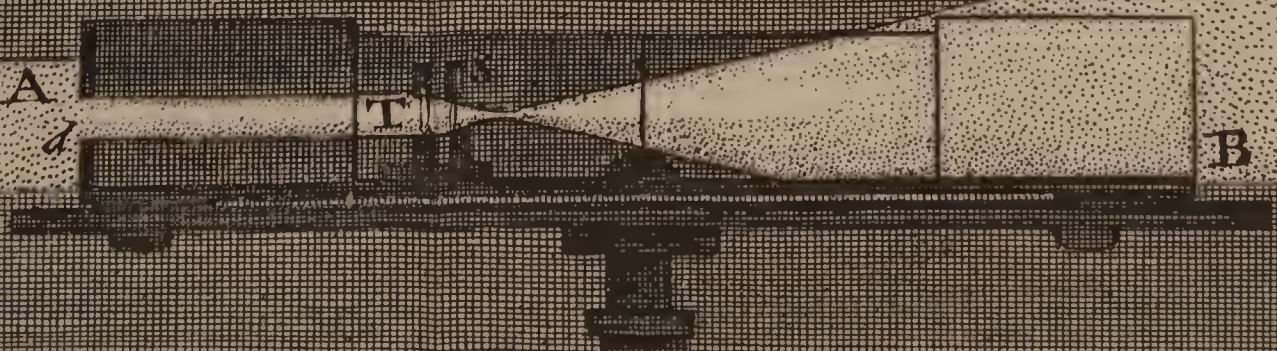


Fig. 4



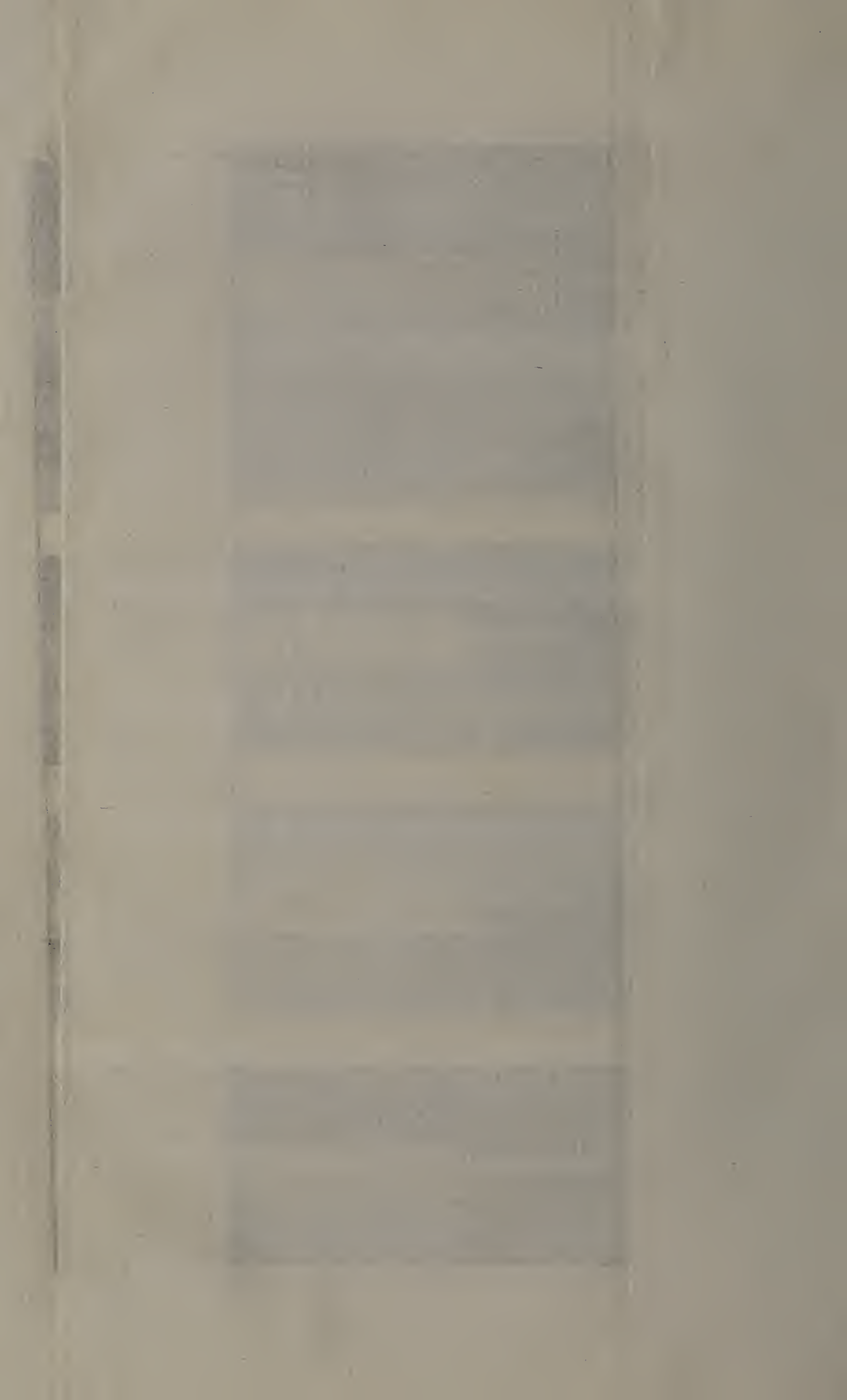


Fig. 1.



98

Fig. 2.

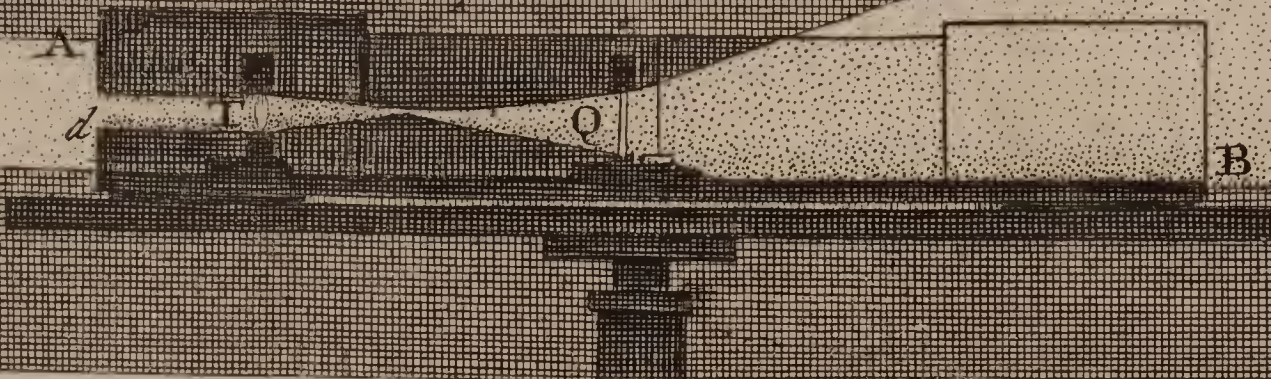


Fig. 3.

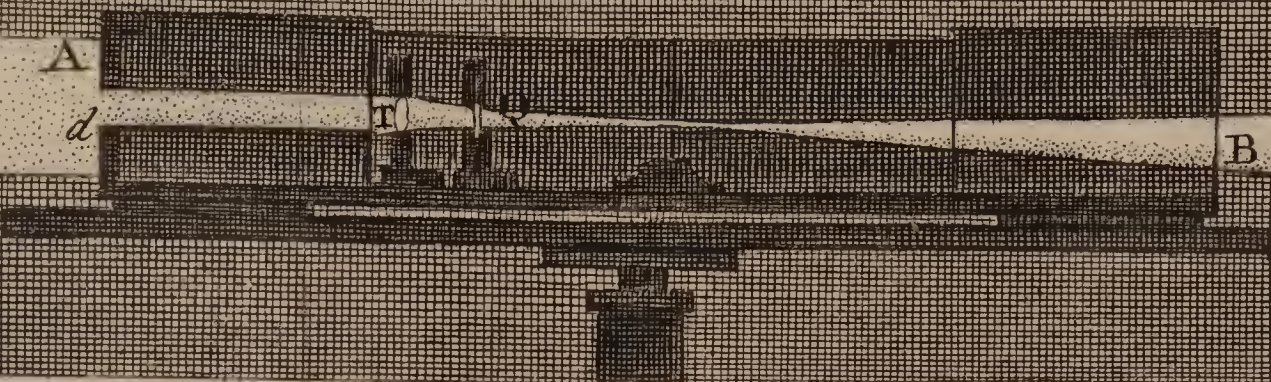


Fig. 4.

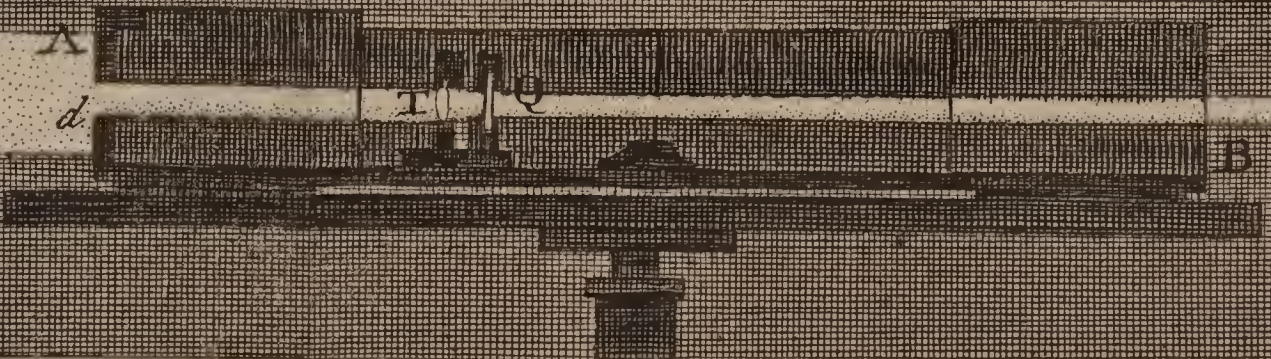
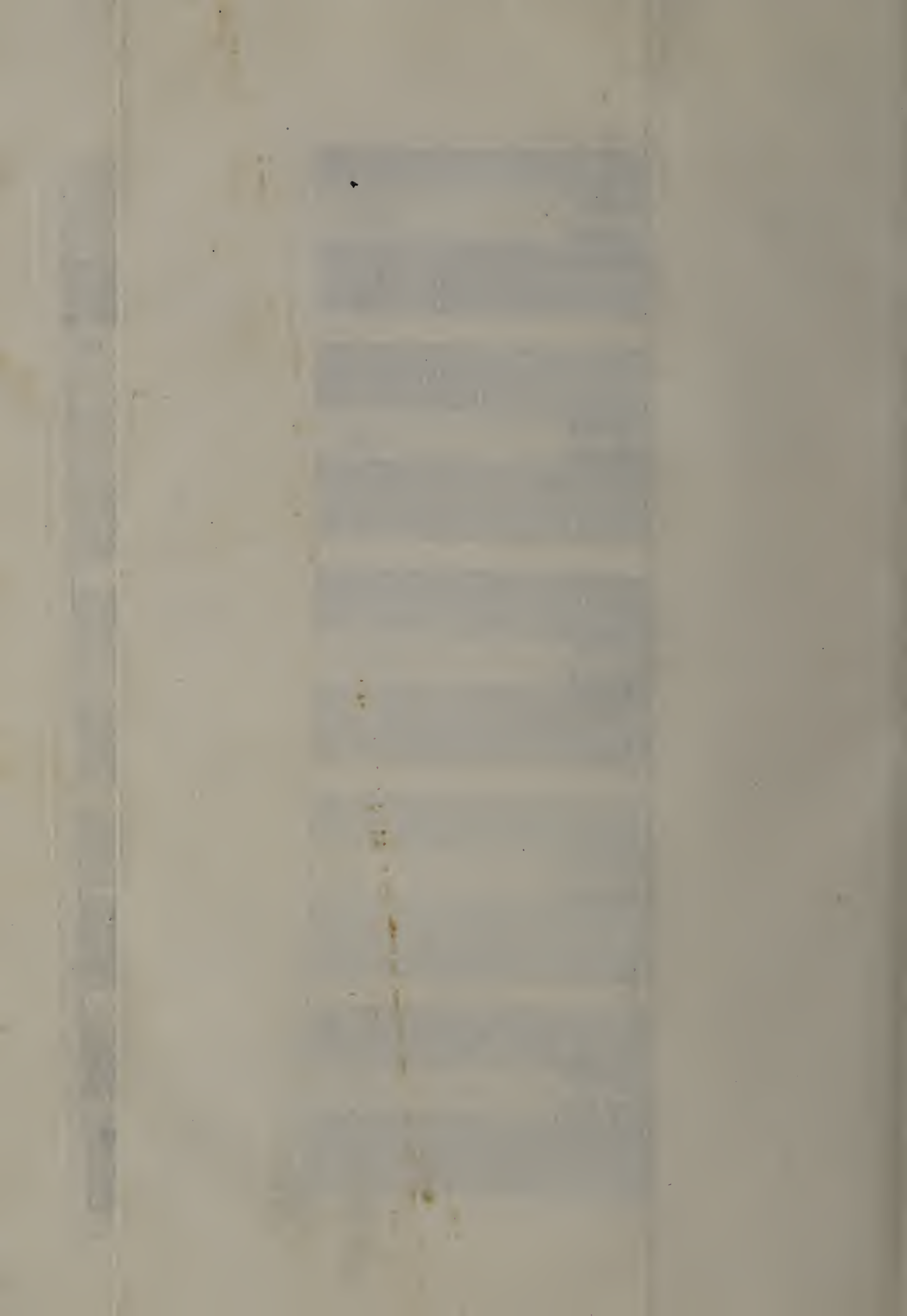


Fig. 5.





EXPERIMENT 4.

This Experiment is made like the first * ; but instead of the Board T we use another Q, that has a concave Lense. Parallel Rays that pass through it, go out diverging.

3023.

Pl. 98.F.1.

* 3013.

EXPERIMENT 5.

All Things remaining, we make use of the Board T also, which we us'd in the first Experiment mention'd * ; by Means of this we make the radiant Point R, from which Rays diverging fall on the concave Lense of the Board Q, and go out more diverging.

3024.

Pl. 98.F.2.

* 3013.

EXPERIMENT 6.

The same Things remaining, bring the Board T towards the Board Q, in such Manner, that converging Rays may fall upon the concave Lense, and when they emerge they will converge less.

3025.

Pl. 98.F.3.

The Board T may be brought so near, that the Rays emerging from the concave Lense will be parallel.

3026.

Pl. 98.F.4.

The Board T being brought still nearer, the Rays going out of the second Lense will diverge.

3027.

Pl. 88.F.5.

We have demonstrated the general Properties of Lenses, I shall now speak of determining the Refractions themselves nicely, but I shall only mention the Propositions, and give the Demonstrations of them in the following Scholiums.

3028.

A Lense being given, that is terminated by two spherical Surfaces, the Point of Concourse, or Dispersion of parallel Rays, is sought.

3029.

The Rectangle made of the Semidiameters of the Surfaces is multiplied by the Number, which expresses the Sine of Refraction in Glass, and the Product is divided by the Difference of the Sines in Air and Glass. This Quotient being divided by the Distance between the Centers, that is, by the Sum of the Semidiameters, when both Surfaces are concave, or convex, and by the Difference, when one is concave and the other convex, there will be given in the Quotient the Distance of the Point sought from the Lense ; which is the same from whatever Part the Rays proceed.

3030.

3031.

The Ratio of Refraction out of Air into Glass is that, which is between 17 and 11 * , nearly as 3 to 2. Therefore we must multiply by 11, and divide by 6 ; or only multiply by 2.

3032.

* 2811.

If one Surface be plane, the Semidiameter becomes infinite, and is had as equal to the Sum or Difference of the Semidiameters ; in this Case the Semidiameter of the spherical Surface is multiplied

3033.

by

by 11, and divided by 6 ; or is doubled, the more accurated Determination being neglected.

3034. The Points, which we discover by these Computations, are the
 * 3007. Points of Concourse, if we consider convex Lenses *, and the
 † 3008. Points of Dispersion if they be concave †.

If direct Rays, either diverging or converging, fall upon a Lense, we discover the Motion after the Passage by this Proportion.

3035. *As the Distance, between the Point, to which the incident Rays come, and the Point of the parallel Rays, proceeding from a contrary Part, is to the Distance between the first of these Points and the Glass itself, so is this last Distance to the Distance between the Point of the incident Rays, and the Point sought of the refracted Rays.*

3036. With regard to which Proportion we observe, that the Point of the refracted Rays is always with respect to the Point of the incident ones at the same Part, at which the said Point of the parallel Rays is with respect to this.

3037. Let R be the Radiant, or imaginary Focus of the incident Rays ;
 Plate 100. E the Focus, or Point of Dispersion, of parallel Rays coming from
 F. 1, 3, 4. a contrary Part ; F the Focus, or Point of Dispersion, of the refracted Rays ; according to the Rule R E, R V, R F, are in continued Proportion.

- * 3030. In the contrary Motion, V e being taken equal to V E *, F e, F V, F R, will be the Proportionals.

3038. What has been said regards direct Rays, one of which coincides with the Axis of the Lense, which in going through keeps it's Direction. But this is not a peculiar Property of this Ray ; *all the Rays that pass through the Center of the Lense keep their Direction also.*

3039. Let V be the middle Point of the Lense ; A B it's Axis ; C D
 Pl. 99. F. 1. an incident Ray, which, being refracted along D E, passes through V ; this, if the Lense be equally convex, or concave, both Ways, will go out of the Glass at E, where the Surface is parallel to the Surface at D, and the refracted Ray E F will be parallel to the incident Ray C D * ; that is, it will go in the same Direction. If
 * 2792. the Lense be thin, the Lines C D and E F make the same right Line to Sense.

3040. If the Lense be unequally convex, or concave, the Point of Intersection of the Rays, not bent, is not in the Middle of the Thickness of the Glass. When one Surface of the Glass is plane, this Point is in the Intersection of the Axis of the Glass and the spherical Surface. In a Lense one of whose Surfaces is concave,

and

and the other convex, the Point, we are speaking of, is without the Lense, on the Side of that Surface, which is a Portion of a smaller Sphere.

If several incident and refracted Rays pass through this same Point, they make two similar Pyramids, which have a common Vertex, in that same Point. 3041.

*If the incident Rays be oblique, parallel, or belonging to a Point, although they be a little dispers'd, when they are refracted, they don't belong to one Point; by Reason of the double Irregularity in the Refraction, the first at the going in, the second at the going out ** 2987. 3042.

But if the Rays become somewhat oblique, and pass through the Center of the Lense, the Refraction does not differ much from the Refraction of direct Rays. 3043.

Let R be the radiant Point in the Axis of the Lense, remov'd from the convex Glas U in such Manner, that it may have the Focus F; let r be the other radiant Point, and rUf the Ray, whose Direction is not alter'd *, the other Rays, which are a little dispers'd, meet with this Ray, at the Distance Vf , which, if rU be equal to RU , does not differ much from UF . 3044. Pl. 99. F. 2. 3038.

If we consider the Thing mathematically, UP exceeds Uf , and the direct Concourse is more perfect, but the Differences are small, as we find, if we attend to what is demonstrated concerning oblique Rays in the foregoing Chapter.

If besides these there are given more radiant Points also, from which also the Rays that are a little oblique fall upon the Glas, the right Lines, which tend from all the radiant Points to their Focus's make two opposite similar Pyramids *, one of which has for it's Base the radiant Points, the other the Focus's of them. 3045. 3041.

If these Focus's fall upon a white Plane, each of the radiant Points illuminates a correspondent Point upon the Plane; and all the Focus's together give an inverse Figure of the radiant Points, such as has been before represented *. 3046. 2977.

EXPERIMENT 7.

We put the Board with it's Lense * upon a moveable Table †; we raise the Table, that the Lense may be at the same Height * with the Flame of a Candle put upon another Table, at any Distance whatsoever. We turn the Lense, that it's Axis may pass through the Flame of the Candle; the Picture of the Candle will be represented inverted upon Paper, placed at a just Distance, and parallel to the Lense. 3047. 2770. † 2774.

3048.

This Picture is the most perfect of all, when the Rays pass through the middle of the Lenſe, but if the Lenſe being cover'd, the Rays be transmitted through the Aperture, a little remote from the Axis of the Lenſe, the Figure of the Flame will be diſtinct enough, by Reaſon of the ſmall Obliquity of the Rays proceeding from the Candle. The Place of the Picture will be the ſame alſo; for the Rays, which, in this Caſe, make the Focus, wou'd meet with the Ray, that is not bent, if this were not intercepted.

EXPERIMENT 8.

3049.

Things remaining as in the laſt Experiment, let the Lenſe be covered with black Paper; three or four ſmall Holes being left in the Paper, whoſe Diameters are equal to a Quarter of an Inch; the Picture of the Flame is repreſented on a white Plane in the ſame Manner as in the foregoing Experiment; but, the Poſition of the Plane being alter'd, we have ſo many imperfect Representations of the Flame, as there are Holes, through which the Light paſſes.

3050.

As by Means of a convex Lenſe we repreſented the Flame of a Candle, ſo we may repreſent the Body of the Sun, by placing a Lenſe in ſuch Manner, that it's Axis may paſs through the Sun; in this Caſe the Sun's Rays which paſs through the whole Lenſe, are

3051.

reduc'd into a ſmall Space, in which Caſe the *convex Lenſe is a burning Glaſs*.

EXPERIMENT 9.

3052.
Plate 100.
Fig. 4.

Let there be a convex Lenſe as U, whoſe Diameter is ſix Inches; let this be directed in ſuch Manner, that one of the Sun's Rays may coincide with the Axis of the Lenſe; if this collects parallel Rays, ſuch as all are to Senſe, which proceed from all the Points of the Sun, at the Diſtance of three Feet, and a Body that is eaſily

3053.

ſet on Fire be placed there, as Wood, upon which the Image of the Sun falls, it will take Fire. But as this Image is not very ſmall, not only by Reaſon of the Magnitude of the Sun itſelf, but alſo becauſe the Picture is imperfect*, by Means of a ſecond convex Lenſe L, through which the Rays become more converging†, the Space is narrow'd in which the Combution is made.

* 2895.

† 3012.

This ſecond Lenſe is chiefly neceſſary, when the firſt Lenſe is large, of the Diameter of two or three Feet. By theſe the Violence of the Fire is greatly increas'd.

SCHOLIUM.

Demonstrations of the Rules, concerning Refractions through Glasses, delivered in Numbers 3030, and 3035.

LET there be a Lenſe U terminated by two ſpherical Surfaces; let C 3054.
and D be the Centers of the Surfaces. Let us ſuppoſe a Ray to be Pl. 99.
given, which coincides with the Axis of the Lenſe, and paſſes along F. 3, 4, 5.
E U R in a right Line; let A B be a Ray at a little Diſtance from it,
and parallel to it, the Point F is ſought, in which ſuch Rays wou'd meet,
after their paſſing through the Glaſs, with the Axis, or wou'd meet being
continued backwards.

Let R be the Point, to which theſe Rays come, whiſt they penetrate
into the Glaſs, that is, R is the imaginary Focus, or Point of Diſperſion,
of the Rays in the Glaſs after the firſt Refraction.

Let E be the Point to which parallel Rays would come, that proceed
from a contrary Part, if they ſhould penetrate into the Glaſs, through the op-
poſite Surface, and continue their Motion in it. Moreover let the Ratio
which is given between the Sine of Incidence in the Air and the Sine of
Refraction in Glaſs, be that which is given between m and n .

We have $EV, EC :: RV, RD :: m, n^*$. * 2919.

By Converſ. and Altern. $EV, RV :: CV, DV$. 2922.

By Compos, or Diviſ. $RE, RV :: DC, DV$.

The ſame firſt Proportion gives by Diviſ. $CV, EC :: m - n : n$;

that is, $EC = \frac{n \times CV}{m - n}$.

The Rays, which in the Glaſs are directed towards R, are in the Air
directed towards F, in ſuch manner, that

$RE, RV :: EC, VF^* :: DC, DV$. * 2930. 2989.

If for EC we put $\frac{n \times CV}{m - n}$ the Proportion is changed into this CD :

$DV :: \frac{n \times CV}{m - n}, VF$; whence the Rule of N. 3030 is immediately
deduc'd.

Let V be the Lenſe; R the Point of the incident Rays; E the Focus 3055.
or Point of Diſperſion of parallel Rays proceeding from a contrary Part; Pl. 100.
F the Focus, or Point of Diſperſion, of the Rays coming to R is ſought F. 1, 2, 3.
of the incident Ray RB, or rB , BF; or Bf is refracted; if EB, or
 eB , be the incident Ray, Ba* will be refracted, and in direct Rays, a* 2789.
little diſperſed, the Angle RBE, or RBe, which the incident Rays
make, is to the Angle, which the Rays refracted in the Glaſs make, as
the Sine of Refraction in Air to the Sine of Refraction in Glaſs: So alſo
the Angle, which theſe laſt in Glaſs contain, is to the Angle which the
Rays refracted in the Air make, that is, to the Angle aBF, or aBf, as
the

* 2809. the Sine of Incidence in the Glafs * to the Sine of Refraction in the Air ;
 17 El. 5. but these Ratios mutually destroy one another ; therefore the Angles are
 BE or BBe, aBF ; or aBf ; to which last BFU is equal. Therefore
 the Sine of the Angle EBR and BFU, have the same Ratio to the Sine
 of the Angle BRU.

* 2923.2924. The first of these Ratios is that, which is given between RE and EB*,
 or EU. The second is the Ratio which is given between RB and FB ;
 or RU and FU ; because UB is small. Therefore

$$RE, EV :: RV, FV.$$

By a Conversion of the Ratio RE, RV :: RV, RF. Which we
 had in N. 3035.

C H A P. X.

*Of the Sight, where we shall speak of the Construction
 of the Eye.*

3056. **T**HE Properties and Laws of the Refraction of Light which
 we have explain'd, are of great use in Objects to be repre-
 sented to our Mind.

By these Laws Objects are painted on the Bottom of the Eye
 very beautifully adorned with their proper Colours ; and this Pic-
 ture is the Occasion of the Ideas, which are excited in the Mind
 with regard to Things seen, as will be shewn in what follows *.

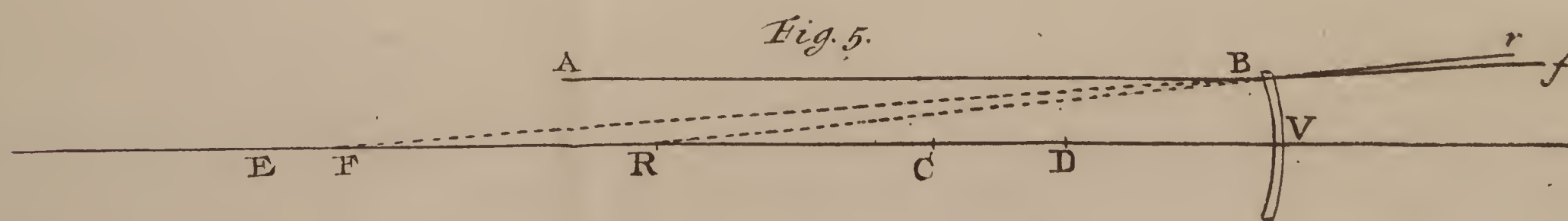
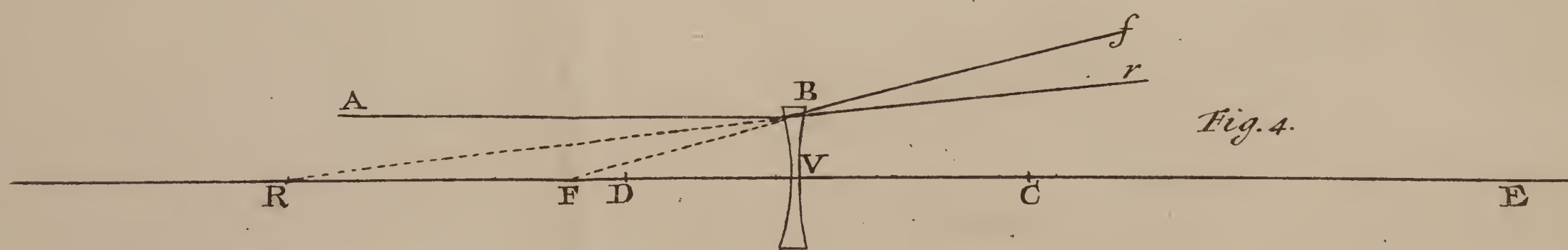
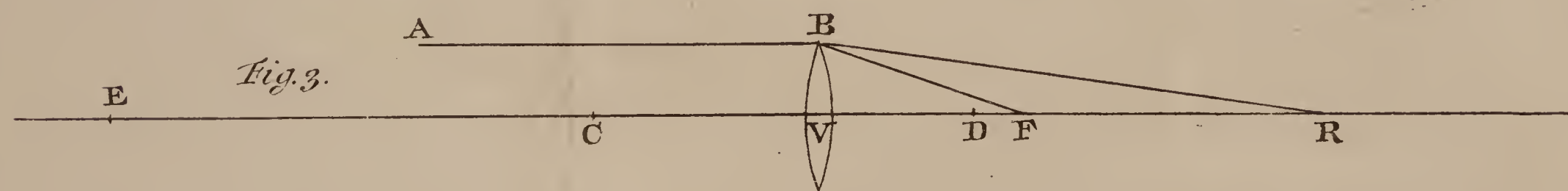
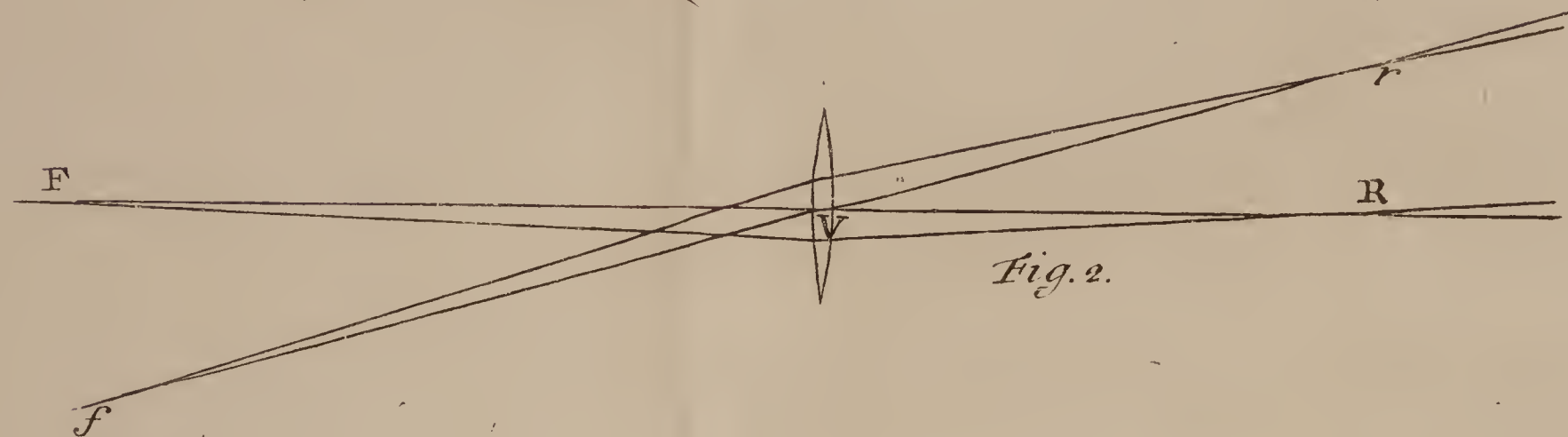
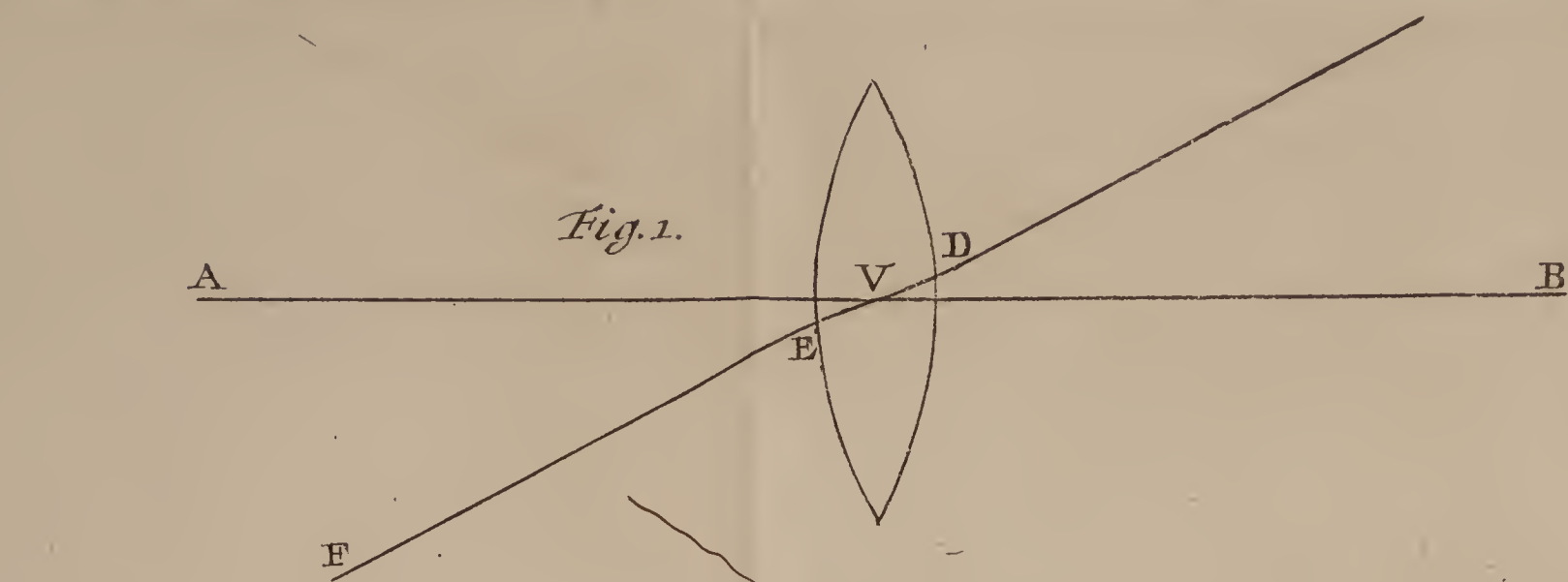
* 3074. But how this Picture may be made in the Eye, cannot be ex-
 plained, without examining the new Property of Light, namely
 the Divisibility of the Rays exceeding our Comprehension.

3057. There are *several opaque Bodies*, when exactly polished, except
 such as are perfectly black, if there be any such, that have the Pro-
 perty of dividing Light ; for they *reflect the Light so, that the Rays*
which are driven back from every Point are divided, and recede
every Way ; and so as every Point of the Body becomes as it were a
radiant Point, from which the Light goes every Way.

3058. Hence we deduce a Method to paint Objects upon a white
 Plane ; for all the Points of an enlighten'd remote Body, from
 which the Rays come upon a convex Lense, have their Focus

* 3011. behind the Lense *, the Foci of distant Objects, though not exact-
 ly, are sensibly at the same Distance from the Lense ; those Objects
 by these Foci may be represented in the same Plane ; as was said

* 3047. before of Flame *. This Representation, as was said of that, is
 inverted, because of the Interfection of the Rays in passing through
 the



the Glafs, and is fenfible in a dark Place in which the Light no Way comes, but through the Lenfe, and only that by which the Objects are painted.

This will do wherever the Lenfe is placed, and in refpect of all the Points of Objects, enlighten'd by the Rays of Light, from which right Lines may be drawn to the Lenfe without Interruption; thus we prove by the fame Experiment the aforefaid Divifibility in Light, and the Aptnefs of Light to be divided by the Bodies that reflect it.

3059.

EXPERIMENT I.

Let there be a Hole in a dark Place oppofite to feveral Objects, that are at leaft fifty feet off, or farther: In this Hole place a convex Lenfe, which collects parallel Rays at the Distance of about four or five feet; if a white Plane be placed behind the Lenfe a little farther from it than the faid Distance, all the Objects will be painted upon it in very beautiful Colours: We muft obferve that by the Motion of the Plane, or of the Lenfe, the Distance is discover'd, at which the Objects are represented very exactly.

3060.

But the extraneous Rays muft be intercepted; to which End, we apply at the Side of the Objects, to the Plane itfelf, in which the Glafs is inserted, a hollow Cylinder, in fuch manner, that the Glafs may be in the Middle of the Bafe, the other End being left open; the inner Surface of the Cylinder muft be made black.

This Representation of the Objects has a great Affinity with that by which the Objects which we fee are painted in the Bottom of the Eye, as will be Evident from the make of the Eye.

The Figure of the Eye, when taken out of the Head, is almoft fpherical; the fore Part only being fomewhat more convex than the other.

3061.
Pl. 100.
Fig. 5.

The Section of the Eye is represented in this Figure.

The Part AA, which is the moft convex, is transparent, and called the *Tunica cornea*.

3062.

The whole Integument, or Covering of the Eye, except the Cornea, is called the *Sclerotica*, B A A B; the fore Part of the Sclerotica, which is next to the Cornea, covered with a thin Coat, is called the *Adnata*; which alfo, by Reason of it's Colour, is called the *white of the Eye*; the Adnata covers the Cornea alfo, but it is fo thin there, as not to be difcovered without Difficulty.

3063.

On the Infide, there coheres a Coat with the Cornea, along the Circumference, called the *Uvea*, which is plane, and has a Hole in the Middle of it *pp*, which is called the Pupil.

3064.

The

The Uvea is made up of concentrical circular Fibres, intersected by straight Fibres, at right Angles tending to the Center; if the first are swell'd, the last are relaxed, and the Pupil is lessen'd or contracted; and a contrary Motion of the Fibres increases or widens it.

3065. In the middle of the Eye, but near the fore Part, there is a transparent soft Body CC, in the Figure of a convex Lense, whose hind Part is more convex than the fore Part. It is called the *chrystalline Humour*; the Axis of it coincides with the Axis of the Eye, that passes through the Center of the Pupil, and that of the Bulb of the Eye.

3066. This chrystalline Humour is sustain'd by small Fibres or Threads, which are fixed to all the Points of it's Circumference, and likewise to the Inside of the Eye: They are bent in Figure of an Arch, and every one of them is a Muscle, being called *Ligumenta ciliaria*, two of which are represented by IC, IC. They all cohere to one another, and together with the chrystalline Humour, make a Separation in the Eye, and divide it into two Cavities, one forward pp, and the other backward SS.

3067. The foremost Cavity is fill'd with a Liquor like Water, and is call'd the *aqueous Humour*.

The hindmost Cavity is fill'd with a transparent Humour, nearly of the same Density with the aqueous Humour, but not so fluid, called the *vitreous Humour*.

3068. The hindmost and inward Surface of the Eye is covered with a Coat, call'd the *Choroides*, which is again cover'd with a thin Membrane call'd the *Retina*.

At the back Part of the Bulb of the Eye, a little on one Side, is the optick Nerve NN, so join'd to the Eye, that the Eye itself is, as it were, an Expansion of the optick Nerve; for the expanded Coats of the Nerve form the Choroides and the Sclerotica; and the Fibres of which the Retina consists, do concur, and form the Marrow of the Nerve.

The Eye moves in the Head by several Muscles cohering in the Sclerotica; but we shall not treat of them here; for as we only consider the Eye, with regard to the Motion of Light, we designedly forbear taking Notice of any Thing else.

3069. *The Rays proceeding from any Point, and entering into the Eye through the Pupil, go out of a less refracting into a more refracting Medium, through a spherical Surface; and therefore if that Point be at a conveni-*

* 2936. *ent Distance from the Eye, the Rays will converge after Refraction* *;
Pl. 96.F. 1. as in the Experiment N. 2978. in which the Glass V represents the translucent Cornea of the Eye, whilst the Water in the Box represents
aqueous

the aqueous Humour; and therefore, *supposing the Cornea, and the aqueous Humour, and there will be in the Eye an inverted Picture of the Objects* *. 3070. * 3057.

EXPERIMENT 2.

Let there be the Box P just mention'd, containing Water; let this be plac'd at the Distance of some Feet from an open Window, through which only Light enters into a Chamber; if at a certain Distance from the Window there be external Objects illuminated with the Sun's Rays, and that be observ'd, which was explained in the 15th Experiment of Chapter 8 *, we shall have at T the inverse Picture of the Objects, as was explain'd concerning the Candle in the said Experiment. 3071. Pl. 100. Fig. 6. * 2978.

The Picture just mention'd in the Eye, an Imitation of which we have in this Experiment, wou'd be at too great a Distance from the Cornea, and beyond the Bottom of the Eye; therefore the Distance is diminish'd *by Means of the chrystalline Humour*, whose refracting Force overcomes the refracting Force of the Mediums that surround it; the Rays converging in the aqueous Humour, go beyond the chrystalline Humour, into the vitreous Humour; that is, from a less refracting Medium, through a more refracting Medium, terminated by two spherical convex Surfaces, into a less refracting Medium; by which Motion the converging Rays converge the more *; and therefore they meet the sooner, *and the Picture* * 3072. 3073. 3012. *abovemention'd falls within the Eye.*

EXPERIMENT 3.

The same Things being given, which were in the foregoing Experiment, put into the Box, at a small Distance from the Aperture, through which the Light enters, a Piece of Wood, which has a convex Glass joined to it, which collects the parallel Rays at the Distance of one Inch in the Air *. To have the Picture exact, The Board T must be mov'd towards V. 3074. Pl. 100. Fig. 6. * 2763.

In this Experiment we have an artificial Eye, which exactly represents the natural Eye. The Glass V represents the Cornea, the convex vitreous Lense represents the chrystalline; the Board T must be look'd upon as the Bottom of the Eye; the Water represents the aqueous and vitreous Humours; for the Light undergoes an equal Refraction in both these Humours. 3075.

The Objects, which, as has been explain'd, are painted upon the Bottom of the Eye, are delineated upon the Retina; and by the Motion of the Light; the small Fibres, of which the Retina consists, are put into Motion; 3076.

Motion ; by which Agitation we see the Objects themselves. But how this happens, must be explained more clearly ; for which End, I shall now add several Things to that, which has been deliver'd above, concerning the Sensations *, where we treated of Sound.

* 2310.

3077.

* 2310.

The Perceptions answer to the Motions of the Nerves *, and indeed in such manner, that, in a well order'd Body, there is never any Motion of a Nerve, without immediately causing a Perception in the Mind.

3078.

Notwithstanding *there is nothing common between the Motion of the Nerve, and the Perception, which answers to it.*

3079.

Therefore *neither is there any Thing common between the Object, which causes the Agitation of the Nerve, and the Perception, that is, between the Perception and the Objects that are perceiv'd.*

3080.

Therefore *the Senses teach nothing of themselves.*

3081.

The Touch alone is excepted ; because this shews the different Resistances of Bodies, from which we immediately learn many Things concerning Bodies.

3082.

All the Sensations have this in common ; that *the same Perceptions are again present to the Mind, as often as the same Circumstances return.*

3083.

Now by comparing together, what we discover by different Senses, relating to different returning Circumstances and chiefly by considering what the Touch teaches us, by long Experience we at last acquire a Faculty, whereby we distinguish many Things relating to external Objects.

3084.

But *we never distinguish any Thing by the Senses, except there be present a peculiar Sensation, distinct from every other ;* which, as it is never regularly present, excepting certain Circumstances *, the Knowledge of which we have acquir'd by long Use, their com-

* 3082.

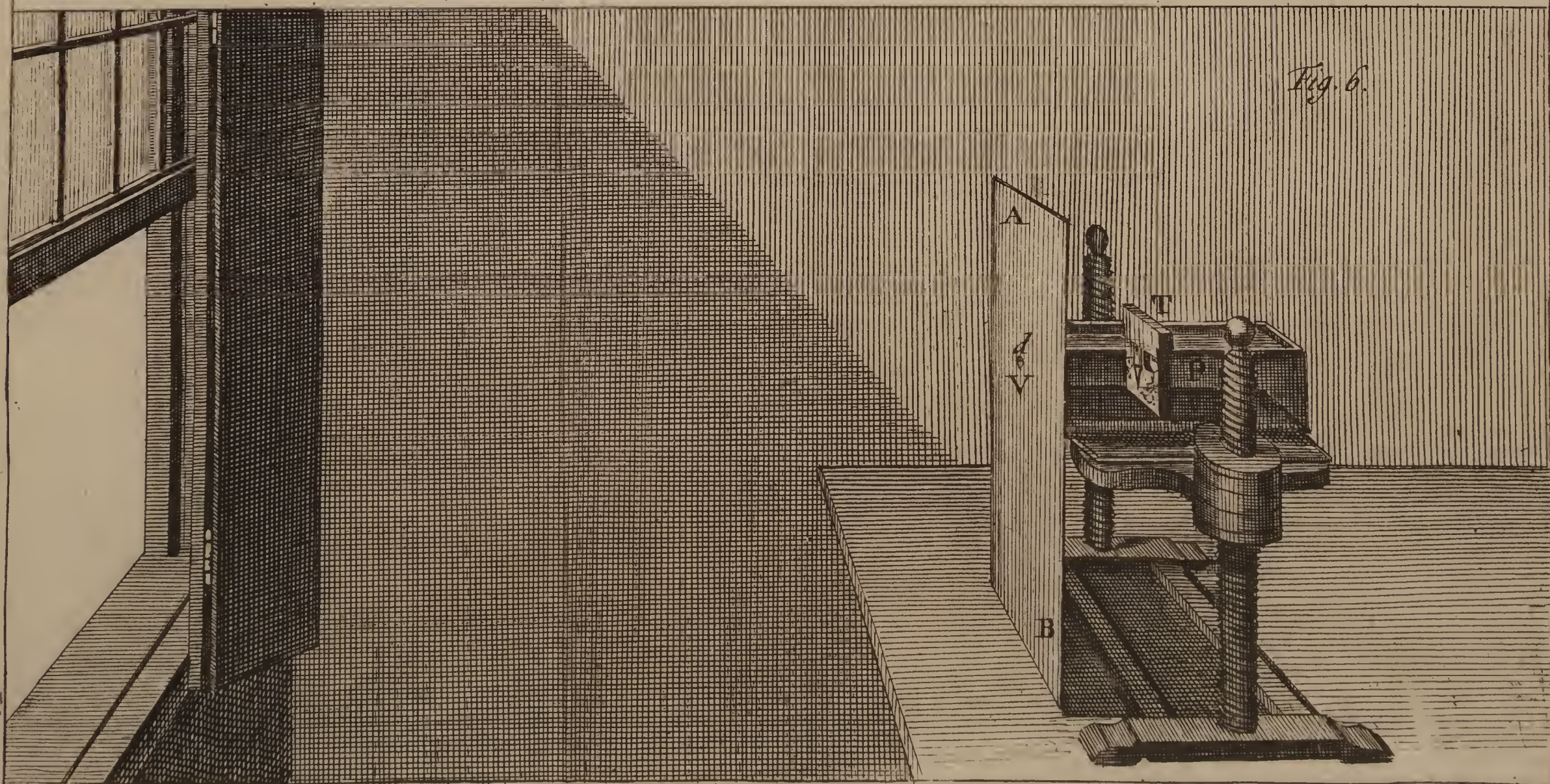
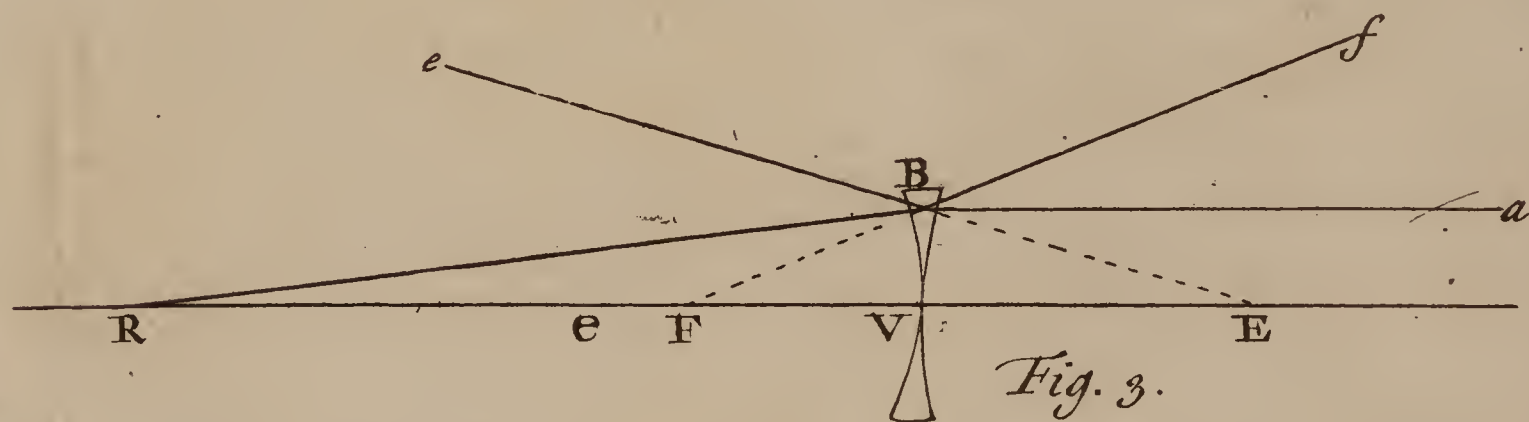
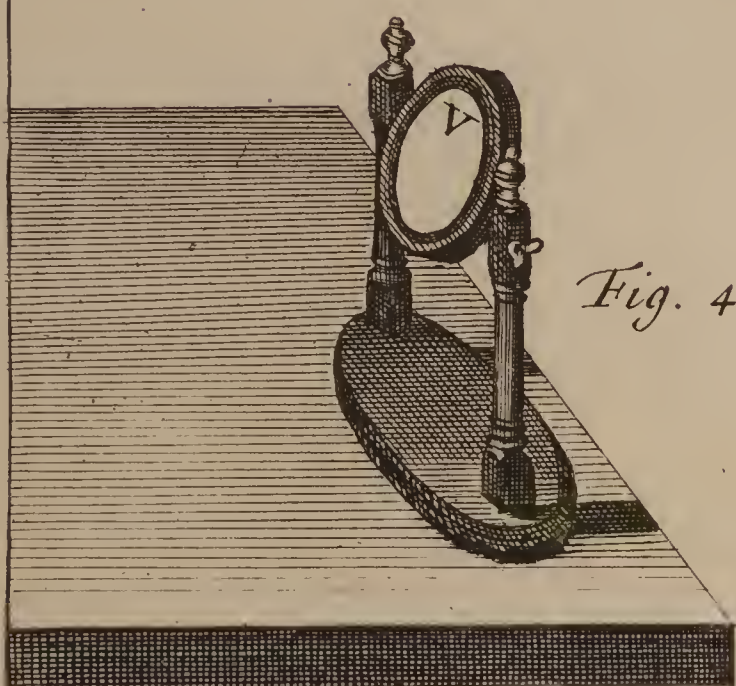
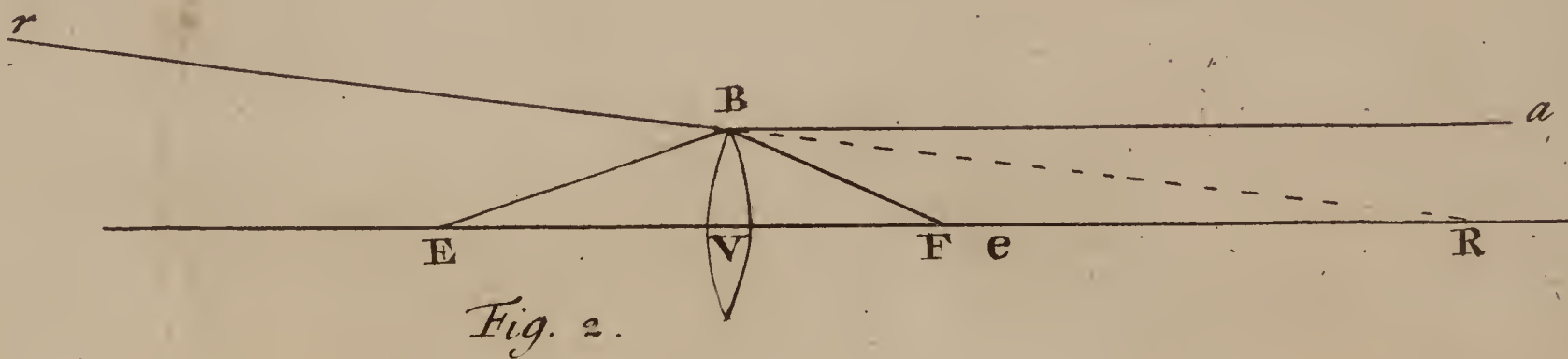
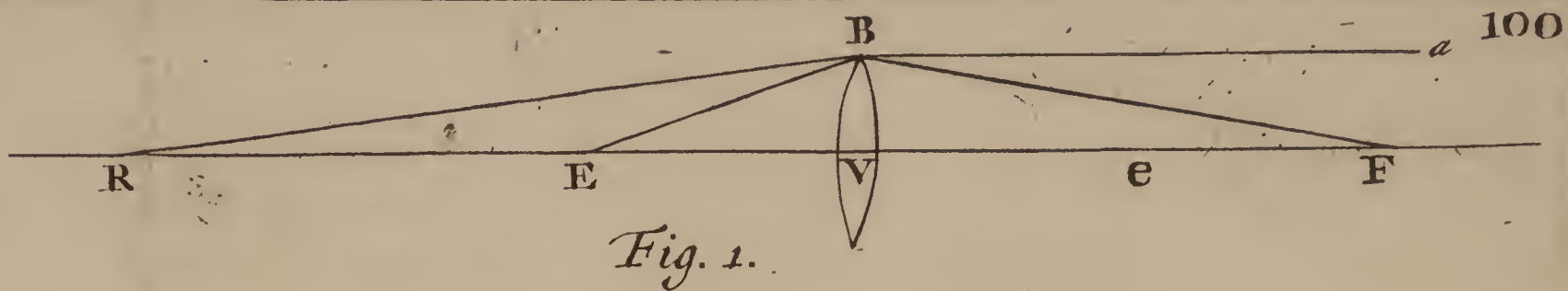
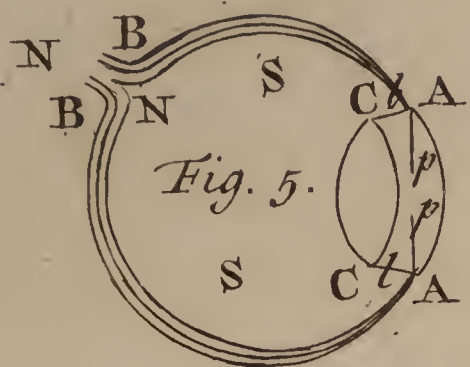
† 3083.

3085.

parison † being shewn, the Idea of the Circumstances, that is, *the Idea of those Things, which we discover concerning an Object, is join'd with the Sensation it self, so as never afterwards to be separated from it.*

In many Cases, Men join together Ideas which have nothing common, which moreover they look upon as inseparable, and which are join'd together by Nature ; but these do not belong to this Place, we have spoken of them in our Logick ; in which also, we have more fully explain'd, what relates to the Senses.

But let us return to Vision. All the Rays, which proceed from one visible Point, meeting where that Point is painted on the Bottom of the Eye, produce there a certain Agitation of a small Fibre distinct from



from every other, and a like Agitation is produced by all the Points of the Object, which is delineated in the Eye.

Therefore Vision is only distinct, when the Objects are accurately painted on the Bottom of the Eye *. 3087.
* 3084.

When Rays, proceeding from the same Point, are not exactly join'd on the Retina, the Picture of it is not a Point, but a Spot, which is confounded with the Pictures of the neighbouring Points, in which Case the Vision is indistinct. 3088.

But as, according to the various Distance of the radiant Point, it's Focus is more or less removed *, it is necessary, that there be a Change * 3089.
in the Eye, that the Place in which the Picture is exact may not fall before or behind the Retina, and that the Vision be not confus'd. 2936.

There are several Opinions of Philosophers concerning this Alteration of the Eye; on which I shall make this general Observation, that it is not at all probable, that the Figure of the whole Eye is alter'd, in order to remove further or bring nearer the Retina, and that the Alteration is to be sought for in the Inside of the Eye. 3090.

For if the Figure of Eye should be changed, as this Change is equally necessary in all Animals, of which we are speaking, the Figure of the Eye will undergo the same Changes in all Animals; for we do not find different Causes of the same Effect in Nature. But in the Whale the Sclerotica is too hard to be liable to Alteration. Moreover if there be such an Alteration in the whole Eye, it will arise from the Pressure of the external Muscles, which are different, according to the different Position of the Eye, and regular in one Case only. 3091.

Besides there cannot be a Change of Figure great enough, that Vision may be distinct at the Distance of an hundred Feet, and at the Distance of two Inches; but there are Men whose Eyes are alter'd enough, to see distinctly in these different Circumstances; which cou'd not be, without almost doubling the Length of the Eye, if we attribute distinct Vision to this Cause. 3092.

Now if we examine the Inside of the Eye, it will appear that the Alteration is necessarily in the Chrystalline; which by a Removal in the Eye, or by an Alteration of it's Figure, will produce the desired Effect; for the Rays, which cut the Retina before they meet, wou'd meet on the Retina if the chrystalline Humour * be- * 3093.
comes more convex; or if, it's Figure being kept, it be carried more to the fore part of the Eye. 3007.

It is plain from this that the Position of the chrystalline Humour is easily altered, and that it approaches towards the Retina, and re- 3094.

cedes from it, it's Axis remaining, because the ciliary Ligaments are muscular: When these Muscles are inflated and become shorter, the Cavity which is form'd at *Cl, Cl*, from the Inflection of these Ligaments is diminished; whereby the vitreous Humour is compress'd, which itself presses upon the chrystalline Humour, and drives it forwards, and increases its Distance from the Retina; which is requir'd in the Vision of near Objects *.

* 2936.3011.

3095. But this Removal is not sufficient; therefore there is also another

3096. Alteration in the Eye. But this second Change belongs to the Chrystalline also; which, *when* it is drawn by the ciliary Ligaments,

3097. whereby *it recedes from the Bottom of the Eye, becomes more plain*; wherefore *there is requir'd a greater Change of Figure, than if it kept it's Position always the same*; that is, the Alteration is more sensible,

* 3110.

† 3112.

which we shall see is of a certain Use *; which nevertheless, in Men that have two Eyes, is for the most part small *.

These Alterations in the Eye have their Limitation, thence also the Objects appear distinct only within certain Limits, at different Distances, according to different Eyes; and very often, in the same Man, but yet have not the same Limits; which is of almost the same Use, as if the Limits for both Eyes were at a greater Distance from one another; for it is sufficient to see an Object distinctly with one Eye only.

3100. In some also the nearest Limit with respect to one Eye is at a greater Distance, than the more remote Limit with respect to the other Eye; in this Case the near Objects, and those that are very remote, are seen distinctly, the intermediate ones appear confused.

3101. The Picture at the Bottom of the Eye is inverted, as has been said *, whence it is enquir'd, why Objects appear erect? To this

* 3070.

we answer by another Question; whether a Person can better conceive the Connection between the Idea in the Mind and an erect Figure, than an inverted one? We must confess that we conceive no Connection in either Case: But by Experience we acquire a Faculty of judging concerning Objects by Means of their Sensation, which always become present, when like Circumstances return *; and it matters not in what Position the Fibres are, if the Sensations in different Circumstances be but different, and the same in the same Circumstances. Our Mind does not behold the Picture being plac'd in a Corner; our Mind joins with certain Sensations, Ideas acquir'd elsewhere *.

* 3082.

* 3085.

3102.

If we behold the same Objects with both Eyes, only one appears; and that in that Case only when the Object is painted on correspondent

dent Points of the Retina. This is by some attributed to the meeting of the optick Nerves; they affirm that in those Animals, who see the same Object with both Eyes, the optick Nerves meet, before they arrive at the Brain to which they arrive when they are separated again.

But this is not the true Cause; for in the Cameleon, who directs one Eye towards the Sky, whilst he beholds the Earth with the other Eye, the Nerves are confus'd in the same manner, as in Man; though generally in Animals, that behold different Objects with each Eye, the optick Nerves are separated from the Eyes to the Brain.

3103.

The true Reason why one Point only appears, is Experience; which has constantly taught us, that the two Sensations arising from correspondent Points of the Nerves proceed from one Point; and thus being join'd together in the Mind, these two Sensations are now join'd with the Idea of a visible Point, so that they cannot be separated by us; as the Sensation, arising from one only Agitation of the Nerve, is confounded with the Idea of a visible Point, and thus it is manifest that the two Sensations may be confounded with the same Idea; if it shall appear by constant Experience, that these always depend upon one visible Point only.

3104.

Therefore the correspondent Points are those, on which the same Point is painted in both Eyes at the same Time. These Points may differ in different Men, they may also vary in the same Man; for if the Position of the Chrystalline be alter'd by a Blow, or any other Way, or if the Eye undergoes any other Alteration, the Picture of the Point may fall upon another Fibre, other Things remaining the same; the Object in this Case appears double; but in a Length of Time this Inconveniency diminisheth, and at last, after a long Experience, vanisheth.

3105.

But in well disposed Eyes the correspondent Points are in Circles parallel to one another, and which, in each Eye, pass through the Point in which the Axis of the Eye passes through the Retina, and in these Circles are equally distant on both Sides from these Points.

3106.

Only one Point can be seen distinctly at the same Time, namely, that which is represented in the Axis of the Eye; this only is painted by direct Rays; in the other the Rays are oblique, and the Vision less distinct *.

3107.

Therefore, when we behold a Point with both Eyes, we direct the Eyes in such Manner, that the Axis of both Eyes continued may meet in it; we easily perceive that this is the Case, when we

* 2987.3012.

3108.

fix our Eyes upon any Point; otherwise we view several Points successively with our Eyes, by directing our Eyes in such Manner, that now one and then another may be distinctly represented in both Eyes; but when this is done on a sudden, instead of all the Points of an Object, not very much extended, we do as it were distinctly see the whole Object at one View.

3109. It is manifest that there are different Sensations, and for various Reasons, from the Light running against the Fibres of the Retina; but these are not sufficient, we ought to have regard to other Things, in the judging of Distances; but that we may discover the Figures of Objects, and judge of their respective Situation; we ought to know the Distances of all the Points from the Eye.

3110. When we behold a Point, the chrystalline Humour puts on a peculiar Figure, which is different, according to the different Distance of the Point, and is always the same at equal Distances*; but as this Alteration of the Chrystalline is inseparable from a certain determined Sensation, *we acquire by Use a Faculty of judging of Distance*; which we always conceive the same as often as there is the same Sensation.

3112. But this is of use only, *when the Distances are small*; for then the Alterations are greater. But *when their Distances are a little greater, the Judgment concerning them is less certain with one Eye*; because as we are less accustomed to judge of Distances with one Eye, the smaller Alterations are not enough sensible to us.

3113. When we behold a Point with both Eyes, we direct the Axes of both to this Point, so that the Axes are more or less inclin'd to one another, according to the less or greater Distance of the Point*. This Alteration of the respective Position of the Eyes is sensible to us, and indeed in such Manner, that it is join'd with Pain if we only consider a near Point remov'd to the Distance of three or four Inches only. Therefore without Attention we acquire by Use a

3114. Faculty of judging of Distance, *from the Direction of the Axes*, which is sensible to us, because it depends upon a Motion of the Eye that is sensible to us. Therefore we see the Use of two Eyes plac'd at a certain Distance from one another; *as long as this Distance of the Eyes has a sensible Ratio to the Distance of Objects the Judgments made concerning this Distance is certain enough.*

3115. Judgment is made concerning great Distances from the apparent Magnitude, Colour, and other Circumstances: If we consider known Objects, which also we owe to Experience; for we call to our Assistance every thing that is known to us concerning an Object, when the Mind judgeth of it's Distance. *It*

Chap. 10. of Natural Philosophy.

181

It is impossible to judge of very great Distances, except the same Object be seen from different Places.

3116.

The apparent Magnitude of an Object, depends upon the Magnitude of the Picture on the Bottom of the Eye; which depends upon the Angle, under which the Object is seen; that is, which is made by Lines drawn from the Extremities of the Object to the Eye.

3117.

The said apparent Magnitude must be distinguished from the Magnitude, which our Mind attributes to an Object seen; this last depends upon the Judgment which is not founded upon that Appearance only; but is deduc'd from all, that is known to us concerning the Object. Every one knows, for Example, that the Object appears the less, according as it is more distant; from whence it is, that according to the greater Distance of the Object, if it be known, the apparent Magnitude of the Object is increased in the Judgment arising in the Mind, which is done indeed without our perceiving it. Therefore the same Object, at the same Distance, appears of a different Magnitude, if we judge differently of the Distance.

3118.

*The Sun and Moon are remarkable Examples of this, which appear greater when they are near the Horizon, than at a greater Height; though, as Astronomers know, the Sun's Picture in the Bottom of the Eye is the same in both Cases, and that of the Moon is less, when it appears greater near the Horizon; we cannot judge of the Distance *; but it appears greater nearer the Horizon, because of the Interposition of Fields and the Heavens. But it plainly appears that this is the true, and only Cause of this Phenomenon, if we look at the same Bodies through a Tube; this apparent Distance vanishes, and with it the Magnitude deduc'd from it. But from our Infancy, and ever after, we get a Habit perpetually of joining the Idea of Distance with the Increase of apparent Magnitude (which is necessary to make a true Judgment concerning the Magnitude) by which these Ideas are so closely connected, that they cannot be separated *, not even in those Cases in which we know * they lead us into Error.*

3119.

3116.

3085.

C H A P. XI.

Of Vision through Glasses, and the Corrections of some Faults of the Eyes.

3120. **A**N Object is visible, because all it's Points are radiant Points *;
 3121. therefore a Point appears in that Place from whence diverg-
 * 3076. ing Rays are emitted †. Except as far as we suppose another Di-
 † 3111. stance, by reason of different Circumstances; for we speak here of
 * 3112. Vision with one Eye only, and the Judgment is uncertain *.
 3122. If Rays any how inflected, enter the Eye diverging, the visible Point
 will be in the imaginary Focus of the Rays, for these Rays enter the Eye
 exactly in the same Manner as the Rays which came directly from
 the Focus would do; and the same Situation of the chrystalline
 Humour is required in order for them to unite in the Retina: So that
 in regard to a Spectator it matters not whether those refracted Rays,
 or those direct Rays, enter the Eye, and there will be the same
 3089. 3111. Motion in the Eye when it fits itself for distinct Vision *.
 3123. A Point appears the more enlighten'd, the greater the Number of
 Rays coming from it is, that enters the Eye.
 3124. I shall say nothing of the Magnitude and Distance, which we at-
 tribute to an Object seen through Glasses; I shall only speak of the
 apparent Magnitude and of the Distances, to which the Points are
 remov'd, from which the Rays seem to come, by which the Points
 of the Object are painted upon the Retina. Every thing else is un-
 certain, and, what is deliver'd by Optick Writers concerning this
 Matter, often contradicts Experience. Different Men, in the same
 Circumstances, judge differently of these Things; and the same
 Man, whilst he beholds equally remote Objects successively through
 the same Glass, the Eye being placed at the same Distance, does
 not always judge of their Magnitude and Distance in the same
 Manner.
 3125. But it appears from other Things how uncertain the Judgment
 concerning Distance is; let any one look at an Object through a
 Glass, and judge of the Distance, and let him place the Object and
 Glass in such Manner, that a Point of the Object may be seen in
 a Limb itself of the Glass, whilst no Part of the Object is seen
 without the Glass; let him also bring near another Object in such
 Manner, that he may perceive this without the Glass, with the
 same Eye, with which he sees the Object through the Glass, and in-
 deed,

deed, so that the Objects may appear join'd, and he may see nothing of this Object in the Glass; and that both Objects may appear in the same Plane; if then, the Glass being remov'd, a Spectator judges of the Distance of the last Object, this will not appear the same as that, which he judg'd of the Object seen through the Glass.

Objects that are seen through a plane Glass, terminated by two parallel Planes, appear to be nearer than when view'd with the naked Eye. 3126. Pl. 101.

Let A be a visible Point; the Rays going from it and entering the Eye are between $A b$ and $A b$; these being refracted in the Glass $V V$, move along $b c$, $b c$; and go out through $c d$, $c d$, which are parallel to the Lines $A b$, $A b$ *: But because $b c$, $b c$ are refracted * 2792. towards the Perpendicular †, $c d$, $c d$, fall between $b A$ and $b A$; † 2787. that is, they cut one another in a , which is less distant than A; therefore the imaginary Focus of the Rays, which enter the Eye, is at a , in which the Point A appears to be *. * 3122.

The said Point also appears more enlighten'd. For all the Rays that are between $A b$ and $A b$ enter the Pupil between d and d ; but since the Lines $A b$ and $A b$ are parallel to the Lines $c d$, $c d$, and these Lines are between those, $A b$ and $A d$ being continued, would fall beyond d , and d ; and so if the Glass was taken away, the Rays which now enter the Pupil would take up a greater Space, and consequently would not all enter the Eye. Every Point that is brought nearer to the Eye, appears more enlighten'd, and thus the Case is in this Matter; for if the Pupil, it's Aperture remaining, should not be at a greater Distance from the Point A, than it is now remov'd from the Point of Disperſion a , the same Rays would enter the Pupil, which follows from the Equality of the Angles $b A b$, $c a c$, made by the parallels $b A$, $c a$, and $b A$, $c a$. 3127.

*The apparent Magnitude of an Object * is increased when seen through a plane Glass.* The Object A E is seen by the naked Eye, Pl. 101. under the Angle $A d E$; but upon the Interposition of the Glass Fig. 2. $V V$, by reason of the Refraction through $A b c d$ and $E b c d$, it * 3117. appears under the Angle $c d c$, which is greater than the last.

The Increase of the apparent Magnitude is the greater, the more the Angles $A d E$, and $c d c$ differ; whose Difference increases with the Accession of the Intersections of the Lines $A d$, $b c$, and $E d$, $b c$, towards the Points b and b ; this obtains in the Accession of an Object towards the Glass; and therefore it is greatest of all, when the Object touches the Glass; which proves that Objects inclos'd in the Glass itself appear magnified also. 3129.

And

3130. And in general, *when the Eye is plac'd in a less refracting Medium, the Object that is seen in a more refracting Medium appears bigger, and by the Refraction is brought nearer too* *. These Things are confirm'd by daily Experience, with respect to Objects seen in Water.

3131. Let there be a Point A seen through a convex Lense V V, the Object being plac'd between the Glas and the Focus of parallel Rays proceeding from the Side of the Eye, the Rays *Ab, Ab*, go out less diverging at *cd, cd*, namely as if they proceeded from *a* *; and therefore the visible Point is remov'd to a greater Distance †. It appears more illuminated also; for the Rays approach nearer to one another by passing through the Glas *, and are reduc'd into a less Space; wherefore they enter into the Pupil in a greater Number also.

3133. The apparent Magnitude of an Object, if the Eye be not applied to the Lense, is also increas'd; that is, the Object, in the Pl. 101. F. 4, & 5. Circumstances mention'd, appears under a greater Angle *beyond the convex Glass*, which is evident by the Inspection of the Figure: The Object A E, seen with the naked Eye, appears under the Angle A d E; but now it appears under the Angle *cdc*, which is greater: For (in Fig. 4.) the converging Rays *Ab, Eb*, do converge more as they go out of the Lense *, or diverging (in Fig. 5.) do come to the Eye converging †, therefore the Object appears magnified; but, as has been already observ'd *, the Magnitude which we attribute to an Object is not in the same Proportion with the apparent Magnitude †.

3135. Objects are not always visible through a convex Glas. For that a Point may appear distinct, it is required that the Rays proceeding from that should enter the Eye diverging *, and that the imaginary Focus of those Rays, in regard to the Spectator, should fall within the Limits of distinct Vision *. If the Object be removed beyond the Focus of parallel Rays, the Rays coming from a Point of the Object, enter the Eye converging *; which Case is impossible to the naked Eyes; in this the Vision is always confused.

3137. If in this Case the Eye be so remov'd, that the Rays, proceeding from a visible Point, meet by Refraction, before they come to the Eye, there are radiant Points in all the Points, in which the Rays meet, namely the Foci of all the Points of the Object, whereby the Object is represented inverted upon a white Plane *, and which are the visible Points with respect to the Eye to which the Rays can come after Intersection *. In this Case the Object appears inverse; because we

do not see the Object itself but the Representation of it behind the Glass, which we said was inverse * ; and we carry this beyond the * 3058.
Glass in Imagination.

We have said that the Case is impossible to the naked Eye, in 3138.
which the Rays coming from a Point enter the Eye converging ;
and so such a Vision is always confused ; because the Make of the
Eye cannot adapt itself to an impossible Case : Yet sometimes, but
rarely, in this Case too, Objects appear distinct ; which as it proceeds
from a Fault of the Eye, by which all distinct Vision is taken away
from the naked Eye, I did not think it necessary to take Notice of
these Exceptions of the general Rule.

The Fault of most Old Men's Eyes is, that they see remote Objects 3139.
distinctly, and near ones appear confused ; which fault *is corrected*
by the Interposition of a convex Lense. The Rays flowing from a
Point which is near meet beyond the Retina ; passing through a
convex Glass, they will diverge less as they enter the Eye, and so
meet within the Eye sooner ; that is, come to the Eye, as if they
came from a Point more remote, such as is seen distinctly by an old
Man.

Objects appear to be nearer, less enlighten'd, and less when seen 3140.
through a concave Glass.

The Rays $A b$, $A b$, and all the intermediate ones, going through 3141.
a concave Lense, become more divergent *, and enter the Eye as Pl. 101.F.6.
if they came from a less distant Point $a \dagger$, to which the visible Point * 3021.
is transferr'd $\dagger$. $\dagger$ 2877.

Upon the increasing the Divergency of the Rays, they are more $\dagger$ 3122.
dispersed, and therefore they enter the Eye in a less Number, which 3142.
lessens the Clearness of the Point *. * 3123.

The apparent Magnitude is also lessened, because the Rays $A b$, 3143.
 $E b$, by which we see the Ends of the Objects, enter the Eye less Pl. 101.F.7.
converging *, and so the Angle $c d c$, under which the Object is seen * 3022.
behind the Glass, is less than the Angle $A d E$, under which it ap-
pears to the naked Eye : Therefore the Object will appear less *. * 3117.

A concave Lense is proper for those who only see near Objects distinctly ; 3144.
such are called Myopes, or are said to be pur-blind ; remote Points
appear through this Lense to be near * ; and the Rays which con- * 3140.
curred before they came to the Retina, now entering more diverg-
ing, do meet upon the Retina.

From all this we see, if we set aside the Clearness of the Objects, 3145.
because through the Glass, as by the naked Eye, it depends upon
the variable Magnitude of the Pupil, that all the Differences may

be brought to two, which are between the Vision through the Lense, and the Vision to the naked Eye; there is a Removal of the visible Point, and the apparent Magnitude of the Object is alter'd, that is, the Picture at the Bottom of the Eye is alter'd. We determine this Removal of the visible Point by the Rule deliver'd in Number 3035, concerning the Refraction of Light in it's Passage through a Lense.

3146. But the Proportion between the Picture, seen by the naked Eye, and this, the Lense being made use of, is discovered by the following Method; from whence it follows that *there is no Difference between these Pictures, when the Eye, or the Object, is apply'd to the Lense itself.*

3147. Let V be a convex or concave Lense, O the Eye; AB the Object; Plate 102. F the Point of parallel Rays, proceeding from the Side of the Object. F . 1, 2, 3. Let there be sought a fourth Proportional VG , to FV , FO , VA ; let G be mark'd in such Manner, that V may be with respect to A and G , as F is with respect to O and V , then OG will be to OA , as the Image without the Glass to the Image of the Object seen through the Glass; and *this Proportion is not alter'd, though the Eye and the Object be transposed* in such Manner that their Places are changed.

3148. In the concave Lense (Fig. 3.) OG exceeds OA , and the Object is diminish'd; if the Lense be convex and O be between F and V (Fig. 1.) the Image is always increased.

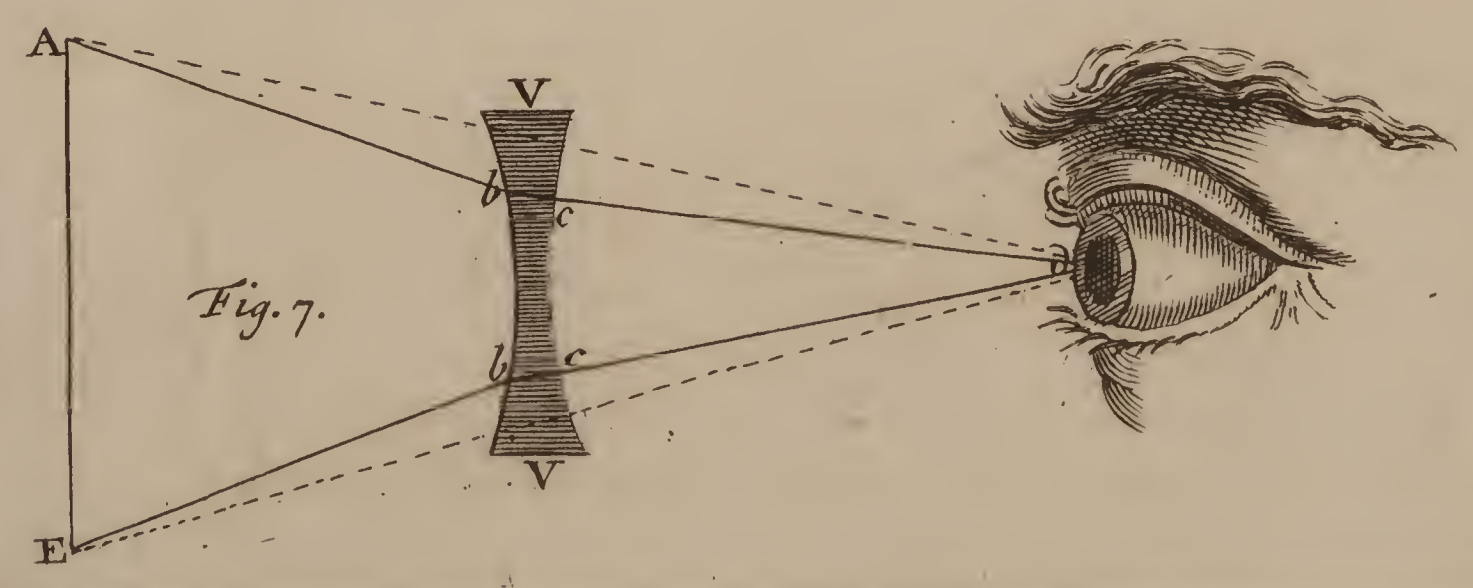
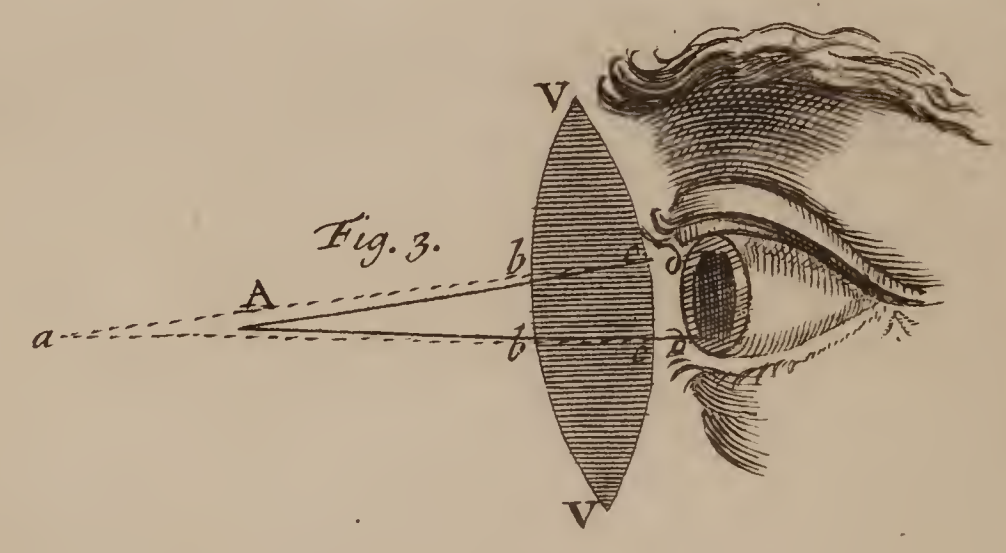
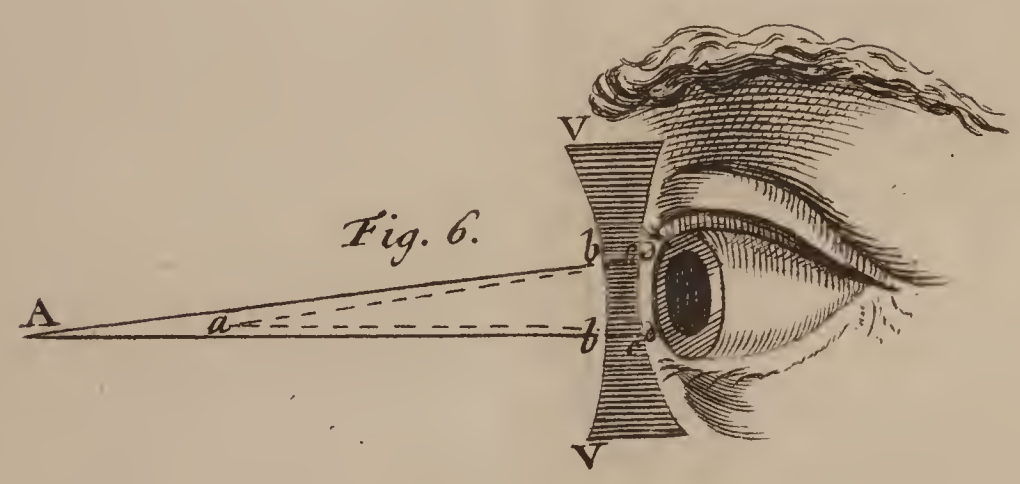
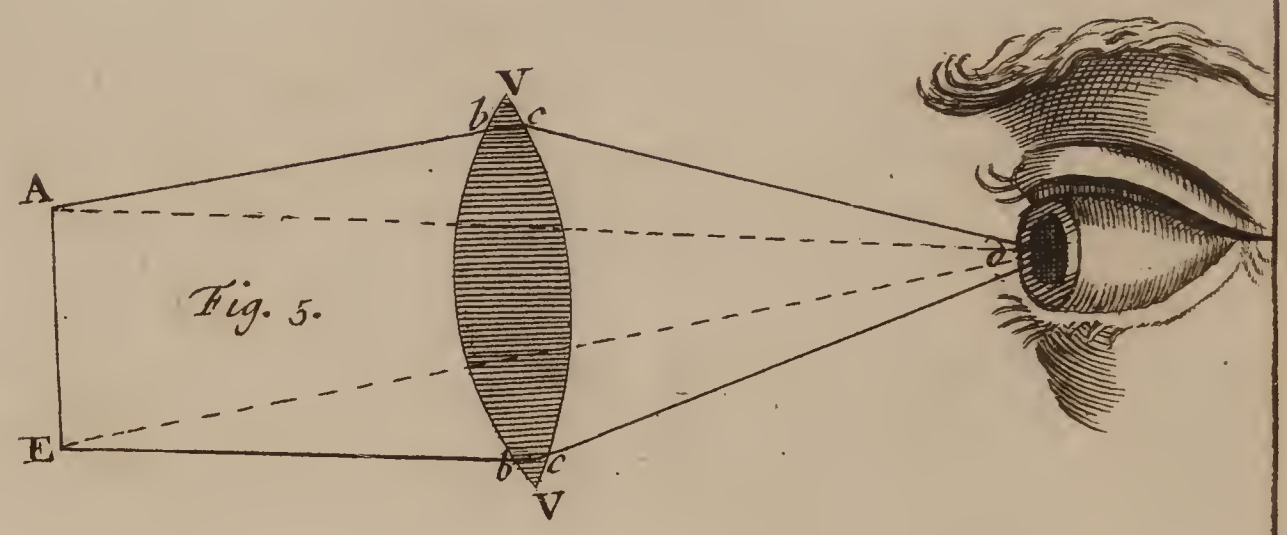
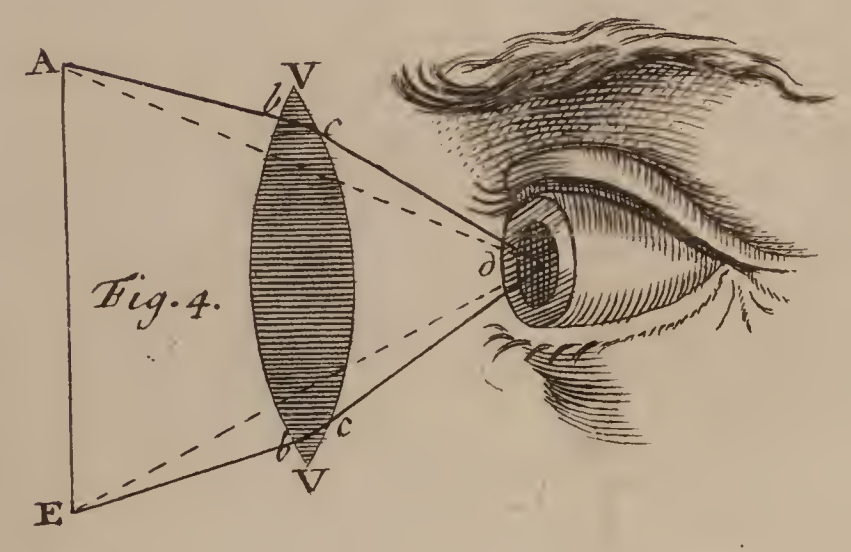
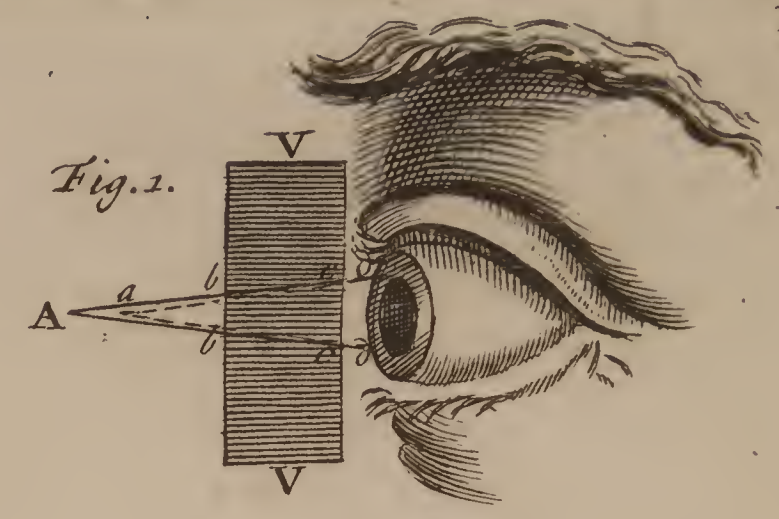
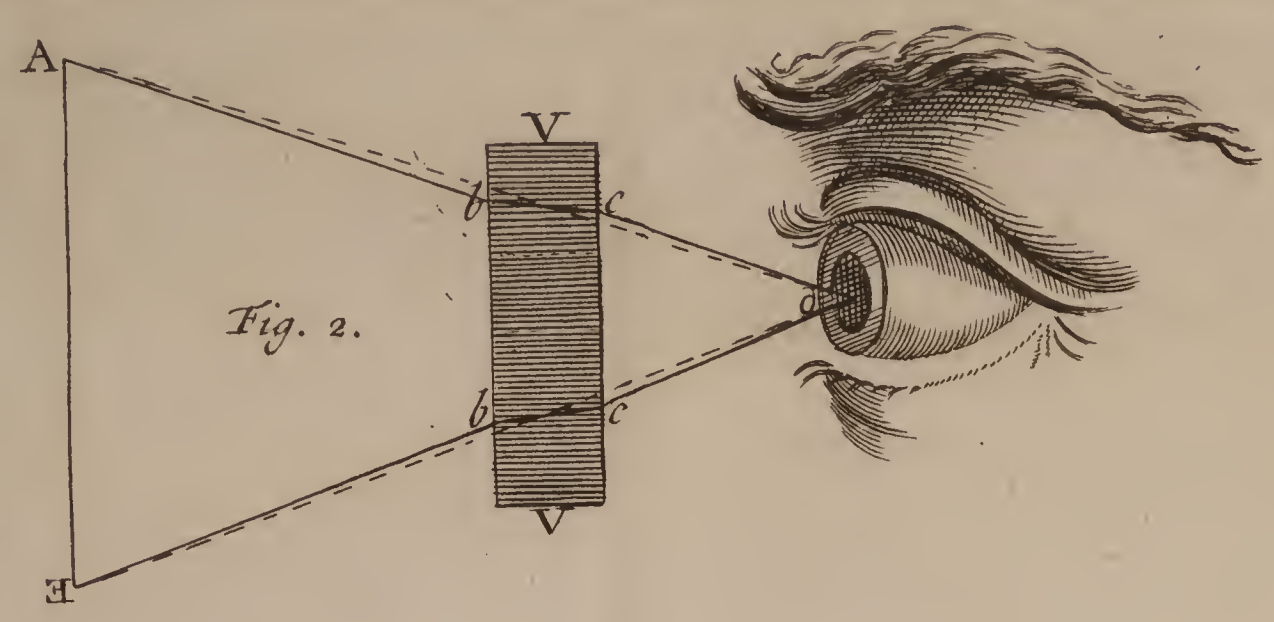
3149. If O coincides with F , G coincides with V , and the Ratio sought is that which is between FV , and FA .

3150. That is, the Eye being placed in the Focus of parallel Rays, the Picture of the Object through the Glass, at what Distance soever we suppose this placed, is equal to the Picture of the same Object seen with the naked Eye at the Distance of the Glass placed

3151. from the Eye; for *the Representation of a Fire seen with the naked Eye encreases as the Distance of that from this is diminished*; for the apparent Magnitude follows the Ratio of the Angle under which the Object is seen *, and this Angle, the Line remaining, which is the Base of it, is diminish'd, as the Base recedes; because we speak of the same Angle.

* 3117. The Eye being remov'd further (Fig. 2.) beyond F , the Phenomena are different according to the different Situation of the Object, as will be seen in the Scholium following; in which we shall demonstrate what has only been mention'd here.

There



There are Glasses that have one Surface plane, and on the other Side there are several plane Surfaces that make Angles with one another; through these the Rays proceeding from the same Point suffer different Refractions; and by every Surface are made to enter the Eye in a different Direction, as if they came from a different Point: That is, the same Point forms several imaginary Foci; and therefore appears multiplied: For it is seen in several imaginary Foci*: Which as it happens in respect of every Point of the Object, *through such a Polyhedrous Lense, the Object appears multiplied.*

3122.
3156.

SCHOLIUM.

Of the Alteration of the apparent Magnitude.

WE have seen that the apparent Magnitude of an Object, seen through a Lense, is alter'd*. I shall now demonstrate the Method, by which I said this Alteration was determin'd†.

3157.
3133. 3140.
† 3148.
3158.

But we must first observe, that the Amplification, or Diminution of an Object, is not the same through the whole Lense; but we neglect a small Difference; we have determin'd the Alteration of that Part of the Object, through which the Axis of the Lense passes; that is, we have consider'd only those Points of the Object, that are near the Axis; of which only I shall now speak.

Supposing what was mention'd in N. 3148. moreover let o be the Point to which the Rays come, which being refracted meet at O , where the Eye is plac'd; therefore drawing Bo , which comes to the Lense at D , the Ray BD is refracted along DO , the Line AB of the Object appears under the Angle DOV ; to the naked Eye the same is seen under the Angle BOA .

3159.
Plate 102.
Fig. 1, 2, 3.

Therefore the Picture in the Eye, when a Glass is put between, is to the Picture in the naked Eye, as VD is to Vd ; whose Ratio is made up of the Ratios of VD to AB , and AB to Vd .

3160.

The first is the Ratio of oV to oA , the second is that between OA , OV .

3161.

We have $VA, VG :: FV, FO$ * : : oV, OV †.

* 3148.

By Alter. Comp. or Divis. and lastly by Invers. $oV, oA :: OV, OG$ †

† 3055.

Therefore the said compound Ratio is made up of these two Ratios of OA to OV and OV to OG , which is the same Ratio as that between OA and OG , as has been shewn in the said N. 3148.

Let us now suppose the Eye and Object to be transposed, the Eye to be placed at A , the Object at O ; the Rays, that proceed from the Point O of the Object, enter the Eye as if they proceeded from o , as follows * from the determination of this Point †; wherefore, instead of the Object at O , we see it's Image at o . In the Case of Fig. 2, the Rays converging from all the Points of the Image, make a confus'd Picture in the Bottom

3162.

2789.

† 3159.

* 3136. of the Eye *, but, as it is manifest, the Magnitude of the Picture of the Image is the same, whether it be before, or behind the Eye, if the Distance and Magnitude of it do not differ.

3163. *The linear Magnitude of the said Image is to the linear Magnitude of the Object itself, as the Distance of that to the Distance of this from the Glass;* that is, as Vo to VO ; as follows from Number 3045; from which we

3164. also deduce in general, that *the Object remaining, the Diameter of the Image follows the Ratio of the Distance of it from the Glass.*

3165. *The Picture of a Line in the Bottom of the Eye, if it be perpendicular to the Axis of the Eye continued, such as the Lines consider'd here, is increas'd and diminish'd with this Line, and follows the Proportion of it.*

The same Picture is increased as the Eye approaches, and the contrary, and it follows *the inverse Ratio of the Distance of the Object from the Eye,*

* 3153. as has been seen above *.

Therefore, in the Case of which we are speaking, the apparent Magnitude through the Glass, that is, the Magnitude of the Picture of the Image, is to the Magnitude of the Picture of the Object in the naked Eye, in a Ratio compounded of the Ratio between oV and OV directly, and of that between oA and OA inversly; which is the Ratio of the Rectangle made of oV and OA to the Rectangle made of OV and

* 23. El.6. oA *, which is the same Ratio that we had above, before the Eye and Object were transpos'd †.

† 3161. Again Let V be a convex or concave Glass, as in N. 3159; O the Eye; o the Point to which the Rays come, which proceed from the Eye; AB the Line of a determin'd Magnitude in the Object, which we suppose moveable.

The apparent Magnitude of the Line AB , to the naked Eye, follows the inverse Ratio of the Distance OA *, therefore, if the Asymptotes being OVA and OE , any Hyperbola, as dg , be described, the Ordinates, as AL , Al , will be to one another as the Pictures of the Object, when it is plac'd at A , or A , for these Ordinates are diminish'd, as the Distance OA is increas'd *.

* La Hire Sect. Con. Lib. 4. Prop. 2. The apparent Magnitude of the same Line AB , seen through a Glass, is as the Angle DOV ; which itself, by reason of the small Line VD *,

3167. follows the Ratio of the Angle VoD , that is, of AoB , under which the Object would be seen, if the Eye were at o . Therefore an Hyperbola

Plate 102. Fig. 1, 2, 3. DG being describ'd at Pleasure, it's Asymptotes being oVA and oe ,

* 3158. it's Ordinates Al , Al , are alter'd as you recede from o , as the Picture in the Eye, when the Object is transfer'd with the Ordinate, and is seen

Plate 102. Fig. 4, 5, 6. through the Glass; as follows from the foregoing Demonstration †.

† 3166. Both the Hyperbolas may be describ'd at Pleasure, as has been said; 3168. but if we would make use of these together in such Manner, that there may be the same Ratio between AL and it's Correspondent Al , of the other Hyperbola, which, in that Position of the Object, is between the apparent Magnitude to the naked Eye, and this through the Glass, we must describe the Hyperbolas in such Manner, that both the Ordinates at

V may

V may be equal, as Vd , VD ; because, if the Object be in this Point, both the Pictures are equal *.

When, the Lense being convex, the Eye is remov'd from the Lense, beyond the Focus of parallel Rays proceeding from a contrary Part, the Point o falls at the opposite Side of the Lense; then if the Object be at o , the Increase of the Picture is infinite. If the Object be then remov'd further from the Eye, the opposite Section gb is of use; for this is the Continuation of the Hyperbola, and it demonstrates by it's Position, that the Position of the Picture in this Point is alter'd, that is, that the Objects appear inverted. * 3147.
3169.
Pl. 102.
Fig. 25.

When OF exceeds FV , the Curve gb cuts dg , these two being continued. We discover the Intersection, if to these two $OF - FV$ and OV , there be sought a third Proportional, for this will determine in the Axis OA , the Distance between the Point O and that, to which the equal Ordinates of the Curves gb , dg , correspond. 3170.

C H A P. XII.

Of Microscopes and Telescopes.

WE have already shewn the Use of spherical Glasses, in correcting the Faults of the Eyes of old Men, and such as are short-sighted *. We shall now consider how they serve in the Discovery of the least Objects, and bringing the most distant, as it were, to the Eye. 3171.
* 3139 3144.

We have already said that convex Glasses magnify the Objects †; which Magnifying depends upon the Refraction of the Rays, as they go through the convex Lense; whence it follows, that it is augmented, if, under the same Circumstances, the Refraction be increased; and this Effect will be obtain'd, by increasing the Convexity of the Lense; which will be the more convex as the Surfaces bounding it are Portions of a less sphere; which can only be had in small Glasses. 3172.
† 3133.

DEFINITION I.

Such small Lenses are call'd Microscopes.

Small Objects are vastly magnified by a Microscope, by Means of which, Things that are invisible to the naked Eye, may be seen very distinctly. 3173.
3174.

DEFINITION

DEFINITION 2.

3175. *The Space seen through the Microscope, that is, the Circle in which Objects are visible through the Microscope, is call'd the Field of the Microscope.*

EXPERIMENT I.

3176. If the small Object A E be view'd through the Microscope V, Pl. 103. F. 1. it will appear magnified at ae *.

* 3131. 3133. But we see Objects through a Glass most distinctly, when we

3177. bring the Eye as near to it as possible, and the Object is placed at a just Distance; which, in the Use of small Lenses, is entirely necessary, otherwise the Field vanishes.

3178. Objects seen through such Glasses appear immensely magnified, yet the Picture has the same Magnitude in the Bottom of the Eye,

* 3147. the Lense being plac'd, or remov'd *; the Amplification in this Case is to be attributed only to the Removal of the Confusion.

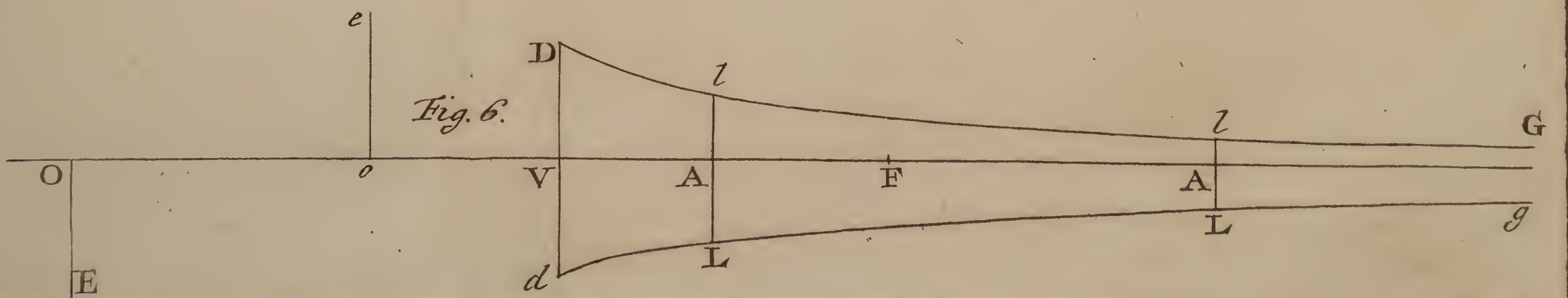
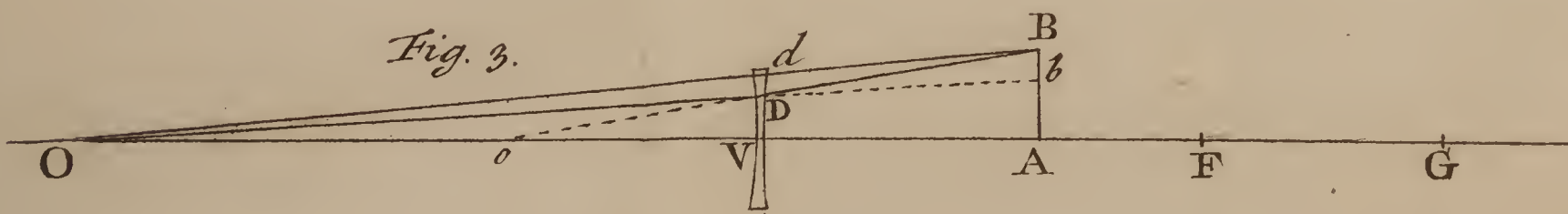
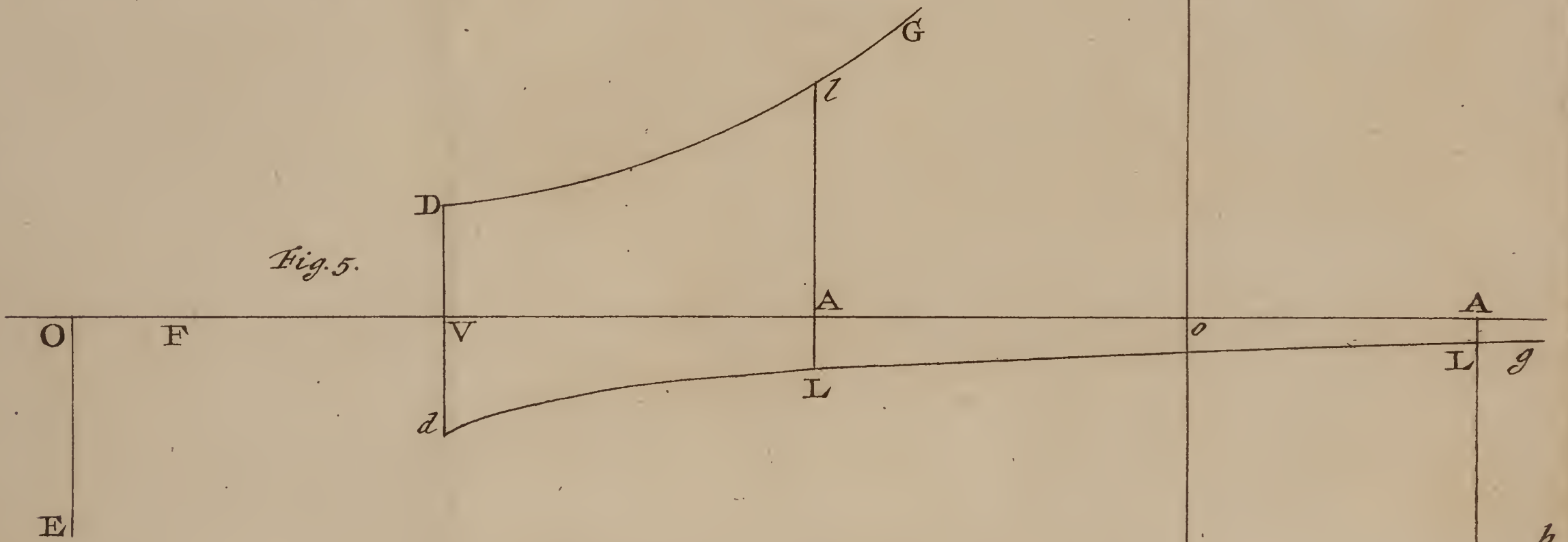
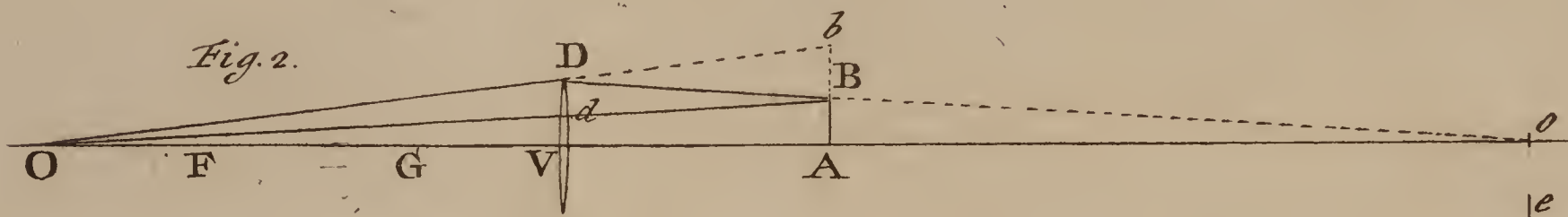
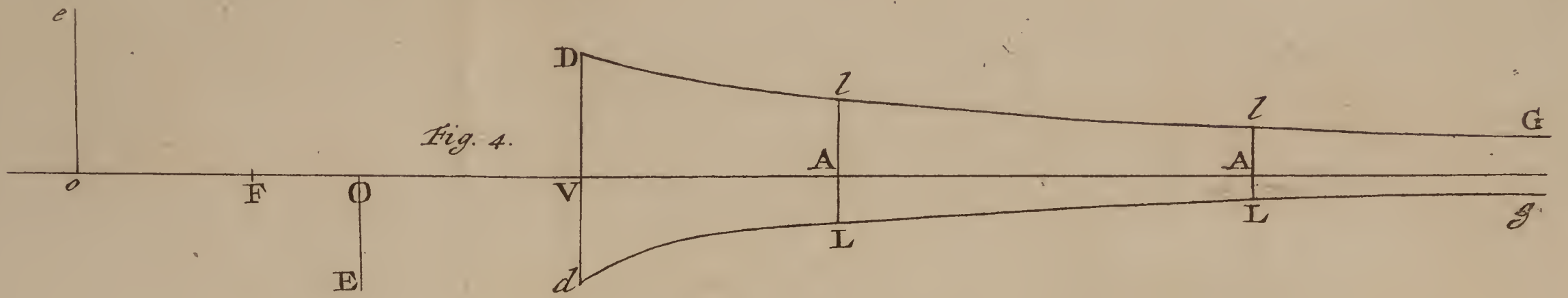
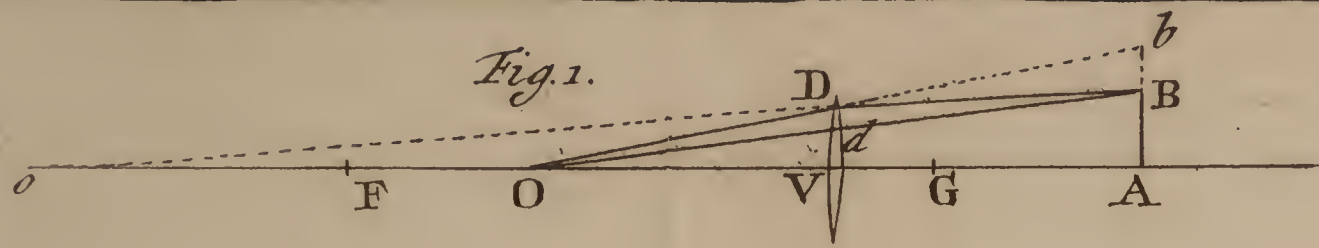
* 3153. Let us suppose a Man, who sees Objects most distinctly at the Distance of seven Inches, let him see a small Grain of Sand, plac'd at this Distance from his Eye, the Picture in the Bottom of his Eye will be very small; let him bring the Grain of Sand so near as to reduce it's Distance to a hundredth Part, and the Diameter of the Picture will be a hundred times as great *; the Vision is confused, or rather, nothing at all is seen plainly, a Lense of due Convexity being plac'd between, the Object is seen distinctly; but as nothing of this happens to the naked Eye, we compare the Magnitude of the Object through the Lense with the greatest, that we perceive with the naked Eyes.

3179. When very small Objects, or the very small Parts of Objects, are examin'd, these single Microscopes are to be preferr'd to others; but the Field is very small, and the smallest Lenses are hardly of any Use, except to those, who by Use have acquir'd the Method of managing both Glasses and Objects.

3180. There are also Microscopes made up of two, or three Lenses, in which the Field is greater than in the single ones, and the Amplification is greater. I shall shew the Foundation of them.

3181. Let there be a small Lense V, very convex, and let there be an Pl. 103. F. 2. Object A E at such a Distance from it, that all the Points of it may have their Focus behind the Glass *; bring the Object so near,

† 3011. that the Foci may be remov'd to ae †; there will be there a Representation of the Object, very much magnified, which will be † 3058. sensible, if it be receiv'd upon a white Plane †.



EXPERIMENT 2.

This Experiment may be well made, by using the Tube of the Microscope, in which transparent Objects, in an horizontal Position, may be strongly illuminated by the Sun's Rays, reflected by a small concave Mirror; which Microscopes are very common in *England*, and now in these Parts also. The Wing of a Fly is plac'd in such Manner, as it should to be seen through the Microscope, and it is strongly enlighten'd; then all the Lenses being taken out of the Tube, one only small one of those, which don't magnify very much, is join'd to it, at the lower End, and a Diaphragm of thin Paper, is fitted in the Middle of the Tube; the Eye being now applied to the upper Aperture of the Tube itself, the Picture of the said Object is seen on the Paper; but the Tube is rais'd or depress'd, till the Representation is distinct, which though it falls on the opposite Surface of the Paper, yet appears vivid enough. 3182.

All the Points of this Representation, which we suppose to be exhibited at *a e*, are radiant Points, and visible *, if the Paper be remov'd. The Rays proceeding from these are transmitted through a second Lense *O O*, and enter the Eye, as if they proceeded from Points at a greater Distance between *a* and *e* †; that is, the Rays proceeding from the Object *A E*, after the Refraction through the two Glasses *V* and *O O*, enter the Eye, as if they proceeded from the Object *a e*. 3183. Plate 103. Fig. 2. * 3121. 3137. † 3131.

Therefore through such a compound Microscope the Object appears inverted, and much more magnified than through the single Microscope. For the Line *AE* through the single Microscope *V*, applied to the Eye, would be seen under the Angle opposite to the Vertex of *a V e*, and is equal to it; but now the same Object is seen under the Angle *O d O*, which is to the first, as the Distance between the Glasses *V* and *O O* to the Distance between this last and the Eye *. 3184. * 3153.

DEFINITION 3 and 4.

In this Microscope the smallest Lense, which is next to an Object, is called the Object Glass, and the other the Eye Glass. 3185.

DEFINITION 5.

The Part of the Surface of the Object Glass, which is not cover'd, that is, through which the Rays, proceeding from an Object, pass, is called the Aperture of the Microscope. 3186.

The

3187. The Eye Glas must not be too small: For the Points of the Representation ae , although they be radiant Points, do not emit Light every way; the Rays which pass through the Object Glas do only intersect one another in the several Points of the Representation ae ; which Representation therefore will not be visible, unless the Rays which go through the Object Glas do also go through the Eye Glas; therefore *the Field depends upon the Magnitude of this Lense.*

3189. *The Eye also must be so plac'd, that all the Rays which come to the Eye Glas, and go through it, may come to the Eye; and this is done by placing the Eye at d , the Point in which all the Rays that come from the Center of the Object Glas, are collected beyond the Eye Glas.*

3190. The Amplification may be further increased, by adding a second
 * 3012. Eye Glas; this is plac'd in the Angle $O d O$, as oo , and the Rays $O d$, $O d$, converge more *, and meet at n , where the Eye must be plac'd. The Position of the Object $A E$ must also be alter'd a little, that the Object may appear distinctly.

3191. Objects appear bright enough through Microscopes, because they are very near the Glas; and so the same Number of Rays pass through a small Lense, as would not pass at a greater Distance,
 3192. unless through a greater Hole. Yet often where the Objects are the most magnified, they must be enlighten'd by Rays collected through a convex Lense, and thrown upon them.

The Astronomical Telescope very much resembles the compound Microscope.

DEFINITION 6.

3193. *Instruments adapted to see distant Objects, are call'd Telescopes.*

3194. That which we now speak of, is call'd an Astronomical Telescope, because it is not fit for seeing Objects upon the Earth; for it represents them inverted; but Astronomers do not much regard the Situation of the Appearance of the Object.

3195. *This Telescope consists of two convex Lenses, the one an Object Glas, which is placed next to the Objects, and the other an Eye Glas, placed next to the Eye. By Help of the first distant Objects*
 * 3058. *are represented at a certain Distance behind the Lense *, as near Objects are in the compound Microscope. If this Representation be observed through an Eye Glas, it will appear enlarged and inverted, as has been said of the Microscope. It is plain also in this Case, as well as in the Microscope, that the Field depends upon*

the

the Bigness of the Eye Glass ; as likewise that *the Place of the Eye is to be determin'd in the same Manner for the Telescope as for the Microscope* * ; and therefore that, by reason of the Length of the Telescope, *the Eye ought to be plac'd in the Focus of parallel Rays of the Eye Glass as to Sense*. For the astronomical Telescope only differs from the compound Microscope, that in the compound Microscope the Lenses are more convex, and so less fit for viewing distant Objects, especially the Object Glasses. In the Microscope the Convexity of the Object Glass is greater than that of the Eye Glass; but in the Telescope it is less.

Telescopes may be as long as possible for observing the Stars ; but when they are above twenty Feet long, they are of no Use for seeing Objects upon the Earth, because of the constant trembling of the Air, which is too sensible in Glasses that magnify much.

A short astronomical Telescope will serve to see Objects upon the Earth, by adding to it two convex Lenses, which are also call'd Eye Glasses.

But the three Eye Glasses are similar, and collect parallel Rays at a Distance double of that, at which the Eye Glass of the astronomical Telescope ought to collect them, the same Object Glass remaining.

Let V be an Object Glass, representing a distant Object inverted at ea ; also let there be three Eye Glasses OO , OO , OO . The first is so plac'd, that the Rays coming from the Points of the Representation ea , may become parallel when they have pass'd through the Lense *. In that Case the Rays which come from the middle Point of the Object Glass, are collected at G ; the second is so plac'd, that these Rays which are collected at G , where they intersect one another, and as it were come from that Point, may go out parallel * ; which being supposed, the Rays coming from the Object Glass to e , and there intersecting, and forming that Point of the Representation, being refracted through the first Glass, pass through G parallel to one another ; they are refracted through the second Lense according to the Direction Oe , and are collected at e^* , so as to make it a Point of a new Representation. In the same Manner the Point a of the first Representation will answer to the Point a of the second ; and since this is true concerning the intermediate Points, the Representation of the Object will be erect at ae .

EXPERIMENT 3.

3202. The two Boards T, T, furnish'd with Glasses *, which collect
 Plate 103. parallel Rays at the Distance of about five Inches, are mov'd upon
 Fig. 4. a Table between two Rulers, in such Manner, that the Axes of both
 * 2772. Lenfes may be in the same Line, in which the Hole also is, through
 which only the Light enters into the Chamber, and in which the
 Object Glas is fix'd, which is contain'd in the short Tube AB, that
 the side Light may be excluded.

The Object Glas is such, that it may represent distant
 Objects inverted at F, at a Distance of about three Feet from A,
 which Representation is seen, if the Rays be intercepted by a white
 * 3058. Plane *. The first Eye Glas is at a Distance of five Inches from
 F, from which the second Lenfe is six Inches distant; at f , at a
 Distance of five Inches from it, there is an erect Representation of
 the same Objects, which is also sensible by putting a white Plane
 between.

Plate 103. The Representation ae is observ'd through the third Eye Glas;
 Fig. 3. the Eye is plac'd at d , in which the parallel Rays aO , eO are
 3203. collected; then we demonstrate that *the Object appears amplified,*
nearer, and erect; for it is seen under the Angle $OA O$, whilst it
 would appear under a small Angle to the naked Eyes, namely, that,
 which is opposite to the Vertex of the Angle eVa .

3204. The Object appears nearer also; not only because the Rays go
 into the Eye, as if they proceeded from an Object ae not very
 remote, but chiefly, because, by reason of the Amplification, we
 diminish the Distance in the Imagination.

EXPERIMENT 4.

3205. Things being given as in the last Experiment; a third Board S
 Plate 103. is plac'd at the Distance of ten Inches from the second Eye Glas,
 Fig. 4. furnish'd with a like Glas; and a fourth Board D, in the Middle
 of which is a Hole d , is plac'd in the same Line with all those, and
 the Distance between S and D is about five Inches. Now if the
 Eye be applied to the Hole d , the Object, as has been said, will
 appear erect, magnified, and near. If the Board D be displac'd,
 that is, be brought nearer or remov'd farther off, the Field of the
 Telescope is diminish'd; because there is but one Situation of the
 Eye, in which all the Rays that pass through the Eye Glasses can
 come to the Eye.

We

Chap. 12. of Natural Philosophy.

195

We are to take Notice that the Eye Glasses, made use of here, are not convex enough in respect of the Object Glass V; but they are best for making the third Experiment.

3206.

We determine the Amplification of the Object in this Telescope, by considering the Increase of the Picture of the Line of any Object, and the Picture is to the naked Eye, to the same, when the Telescope is used, whether one Eye Glass be used, or three equal ones, as the Distance, at which the Eye Glass collects parallel Rays, is to that, which is between the Object Glass and the Eye Glass next to it; for so are the Angles under which we see the same Line with the naked Eyes and through the Telescope; for the first is vertical to OVO , and the second is $O d O$, as has been said above.

3207.

All the Points of the Object do also appear more enlighten'd: For the Rays which, coming from any Point of the several Points of the Object Glass, do intersect one another in a Point of the Representation, by Reason of the small Distance of the Eye Glass from that Representation, are but little dispers'd before they come to the Eye; so that they all go into it. And therefore *the Illumination, given by the Telescope, is to that which is given by the naked Eye, as the Surface of the Aperture of the Object Glass, through which the Rays pass, to the Surface of the Pupil* *.

3208.

* 3123.

One may also with two Lenses make Telescopes, which shall shew Objects erect, enlighten'd, and magnified. These must be shorter; for if they be above one Foot long, they become almost useless.

3209.

Let V be an Object Glass; the inverted Representation of a distant Object will be at ea *: The Rays are so intercepted by the concave Lense OO , that such of them, as come from the Center of F. 5. the Lense V, are inflected as if they proceeded from the Point f †; * by the same Refraction the Rays, which concur'd at a , become † diverging †, having their imaginary Focus at a ; which also happens in respect to all the Points of the Representation ea , and instead of it, you have an imaginary Representation which is erect at ae ; that is, the Rays enter the Eye as if they came from the Object plac'd at ae .

3210.

Plate 103.

* 3058.

† 3021.

† 3022.

The Rays, in all respects, go out diverging from the Eye Glass; and therefore *the Eye must be brought as near as possible to the Eye Glass*.

3211.

The Field in this Telescope depends upon the Magnitude of the Pupil; the Magnitude of the Object Glass must also be consider'd; for often, in a short Telescope, furnish'd with a large Object Glass, the Rays, which come from a Point of an Object oblique-

3212.

ly to the Center of the Lense, don't reach the Pupil, whilst the other Rays, proceeding from the same Point, which pass through the Lense near the Circumference, go into the Eye.

3213. The general Theory of Microscopes and Telescopes being explain'd, I shall add something concerning the Perfection of these Instruments; I shall speak chiefly of Telescopes, most of which may be applied to Microscopes.

3214. The Use of an Object Glass, is to make a Representation of a visible Object, which we observe through an Eye Glass: The greater this Representation is, the more distinctly the small Parts of an Object may be seen. But the Magnitude of this Image, as long as we consider the same Object, follows the Proportion of the Distance,

* 3164. at which it is from the Lense *. In an Object at a great Distance, such as we now consider, the Rays, proceeding from any Point,

3215. are Parallel to Sense, and the Image is remov'd to *the Distance, at which the Object Glass collects parallel Rays; we call this the Length of the Telescope.*

3216. *The first thing therefore requir'd to the Perfection of Telescopes is, that they be long, yet we must have regard to what has been ob-*

* 3198. *served above of this Length *.*

3217. The said Image must be enlarg'd by Help of an Eye Glass as much as possible, that the Picture of the Object in the Eye may be as great as possible; but all the Light, whereby the Image is made, always goes into the Eye; therefore, *when the Picture is enlarg'd, when the Light is not increas'd, the Picture is darken'd, in the Ratio of it's Increase; for the same Light is spread more.*

3219. Whence it follows that the Light, whereby the Image is made, must be first increased as much as possible, and then the Eye Glass must be so convex, that the Amplification may be as great as possible, the Clearness remaining.

3220. The Light that tends to all the Points of the Image, passes through all the Points of the Aperture of the Object Glass; and therefore *the Illumination of the Image is proportional to the Surface of this Aperture.*

3221. But this Aperture is circumscrib'd in narrow Bounds for two Reasons. The Rays proceeding from a Point, are collected into one Point only, when they are a little dispers'd, for otherwise the Representation of the Point is a Spot; as follows from what was

* 2895. *said elsewhere *.*

But the Dispersion of the Rays from this Cause is neglected; because the Spots, that make the Image, if they do not increase beyond

yond a certain Magnitude, are not noxious; but before they come to that Magnitude, by dilating the Aperture, the Image is already confus'd for another Reason; wherefore we only consider the second Cause of the Dispersion of the Rays, proceeding from the same Point.

Every Ray is subject to this Law of Refraction, which I shall explain more fully in the fourth Part of this Book; for a Ray is so divided, and dispers'd, when bent by Refraction, as to fill the Plane of the Angle, which is in the Ratio of the Bending of the Ray, at least in all those Cases, of which I now speak.

3222.

When the Aperture of a Telescope is enlarg'd, the Dispersion of the most distant Rays increases, and this is easily so increased, that the Image will become quite confus'd; but Experience alone can teach us, how far the Spots may be increased, and the Image be kept distinct.

3223.

Now if we suppose this to be determin'd by Experience, we must return to the Illumination *; but in order to determine this, * we must not seek such an Eye Glass, as, when the Aperture and Length of the Telescope are given, extends the Picture in the Bottom of the Eye in such Manner that the Clearness of a distant Object in the Telescope may agree with the Clearness of the same Object, brought so near to the naked Eye, that the Picture may have the same Magnitude as in the Telescope. But Experience has shewn with regard to the Day that a sixth Part of the Light, which should be thus determin'd, is sufficient, that an Object may appear enlighten'd enough; in the Night much less Light is sufficient, because the Fibres of the Retina are more easily mov'd then, for so they constitute themselves, when the external Light is diminish'd. This is the Reason of the Difference, mention'd above, between the Eye Glasses of the Telescopes which are used in the Day or in the Night *. When the Eye Glass is twice as acute, as has been shewn there, the Clearness is reduc'd to a fourth.

3224.

3219.

3200.

Therefore all that is requir'd to the Perfection of a Telescope, when it's Length is given, must be determin'd by Experiments, that is, by Trials. But these Trials suffice for one Telescope. For if the Length of the Telescope, it's Aperture, and the Distance at which the Eye Glass collects parallel Rays be given, we discover by Computation the Construction of a Telescope of any other Length whatsoever, which exhibits what is visible as distinct, and clear as the first.

3225.

3226. To avoid Confusion we spoke *, as if the Trials which relate to the Magnitude of the Spots, mentioned in N. 3220, might be made without having regard to the Eye Glafs; but it is not so, for the Confusion depends upon the Magnitude of the Picture of this Spot, and this Picture is different according to the different Figure of the Eye Glafs.
- * 3223.
3227. The Trials therefore must be so made, that different Eye Glasses may be used for each of the Apertures.
3228. *Huygens* for nocturnal Observations determin'd an Aperture, whose Diameter is three Inches, when the Length of the Telescope is thirty Feet; and he gave an Eye Glafs, whose Focus of parallel Rays is distant from it three Inches and a Tenth. Yet it must be observed that Object Glasses, except they be very well work'd, can scarce bear so great an Aperture, and that most Spectators require more Clearness; and therefore a less acute Eye Glafs must be used; though *Huygens* himself sometimes used Glasses more acute, than he should have done according to the following Rule.
3229. If the Length be alter'd, *the Aperture must be alter'd in such Manner, that it's Diameter may be in the subduplicate Ratio of the Length, and the Distance of the Focus of parallel Rays in the Eye Glafs must be alter'd in the same Ratio.*
3230. When Objects are more clear, the Light, which in the Margins of the Spots did not affect the Fibres of the Retina, acts upon the Eye; and to avoid Confusion the Aperture of the Telescope must be diminished: But if this be too small, the Objects do not appear exactly terminated, also when too much Light remains; the Cause of which Phenomenon is not yet sufficiently known: In these Cases, the Eye Glafs must be colour'd with Smoke, to remove the too great Clearness.

S C H O L I U M.

The Demonstration of the Rule delivered in N. 3229, concerning the Determination of the Apertures, and the Eye Glasses of Telescopes.

3231. THE Clearness of a Picture in the Eye, of an Object seen through
- * 3220. a Telescope, is as the Aperture of the Telescope *; it is also in
- † 3218. the inverse Ratio of the Surface of the Picture itself †. But the Diam-
- * 3214. 3215. eter of it is directly as the Diameter of the Image itself, which is as the
- † 3 52. 3165. Length of the Telescope *, and inversly as the Distance of the Focus of
3197. the Eye Glafs †; but the Picture itself is in the duplicate Ratio of the
- || 20. El. 6. Diameter ||. The Ratio compounded of these three, the two last being
- 2 El. 12. inverted,

inverted, is the duplicate direct Ratio of the Diameter of the Aperture and the Distance of the Focus of the Eye Glafs, and the inverse duplicate Ratio of the Length of the Telescope. Therefore in order to compare together the Clearness of different Telescopes, we must in each multiply the Diameter of the Aperture by the Distance of the Focus of the Eye Glafs, and divide the Product by the Length of the Telescope, and the Quotients will be to one another in a subduplicate Ratio of the Clearness.

Now if according to the Rule the Length of the Telescope be as the Square of the Diameter of the Aperture, and this Diameter be as the Distance of the Focus of the Eye Glafs, the Product of these two Quantities, will be as the said Length; so that the said Quotient will be the same, and the Clearness the same, for all Telescopes.

An Object will be seen equally distinct through different Telescopes, if the Magnitude of the Spot in the Eye, which exhibits the visible Point, be the same *. 3232.

Let there be the Rays B A, B A, proceeding from the same distant Point, and passing through the Object Glase V, in the Margin of the Aperture; *the Diameter of the Spot in the Image in the Telescope* increases, as the Dispersion of these Rays, that is, as the Angle $f A f$, and as the Distance V F, which is the Length of the Telescope *. The Angle $f A f$ is in the Ratio of the Angle A F V †, and this is, as to Sense, in the direct Ratio of the Semidiameter of the Aperture V A, and the inverse Ratio of the Distance V F; therefore the Ratios being join'd ff is in the direct Ratio of the Length V F, and the Semi-diameter, or whole *Diameter* *, of the Aperture, and lastly the inverse Ratio of the same Length; the first and third of these mutually destroy each other, and only the middle one remains. * 3223. P. 103. F. 6. 3233. 3215. 3222. 15. El. 5.

The Picture of the Diameter of the Spot in the Eye is in the direct Ratio of the Diameter of the Spot in the Image *, that is, of the Diameter of the Aperture †, and the inverse Ratio of the Distance of the Focus of parallel Rays of the Eye Glafs ||. 3234. 3165. 3233. 3152. 3197.

Therefore, as these Ratios mutually destroy one another, the Picture of the Spot is not alter'd, and the Point through all the Telescopes, made according to the Rule, appears equally distinct. 3165.

B O O K V.

PART III. Of the Reflection of Light.

C H A P. XIII.

Of the Reflection of Light, and the Law of it.

3235. **W**E have shewn that Light is reflected from opaque Bodies,
 * 3057. and that every Point reflects it every Way *. The Occa-
 sion of this is the Inequality of the Surfaces, which are made up of
 an innumerable Quantity of small Planes, which, in all sensible
 Points, are directed every Way; which will be easily conceiv'd, if
 we imagine a Surface cover'd with an innumerable Quantity of small
 Hemispheres. That this is true we deduce from the Reflection of
 3236. Light from a *polish'd Surface*; that is, from a Surface whose In-
 equalities are taken off; which *in all it's Points reflects the Light only*
one Way, which obtains in curve as well as in plane Surfaces: Nay,
 from Surfaces that are not at all polished, the Light is mostly re-
 flected that Way, that it would be all reflected if they were polish-
 ed, as daily Experience shews.
3237. Let AC be a Ray of Light coming obliquely upon a plane Sur-
 Plate 104. face; let CO be perpendicular to this Surface, and the Rays be
 Fig. 1. reflected along CB .

DEFINITION I.

3238. *The Ray CB is call'd the reflected Ray.*
- * 1162. *The Angle OCB is call'd the Angle of Reflection *.*
3239. *The reflected Ray is, together with the incident Ray, in the same Plane*
which is perpendicular to the reflecting Plane.
3240. *For the Action of this Plane, by which the Light is reflected, is*
directed perpendicularly to the reflecting Plane, which is supposed
alike in all Points.
3241. *The Angle of Reflection is equal to the Angle of Incidence.*

Fig. 1.

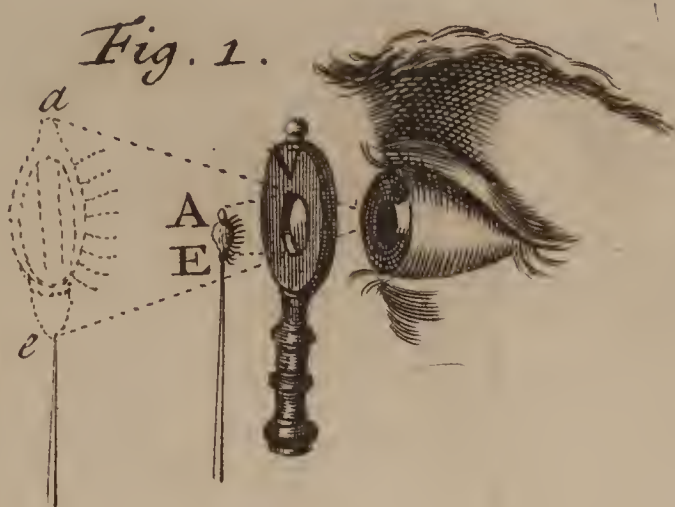


Fig. 2.

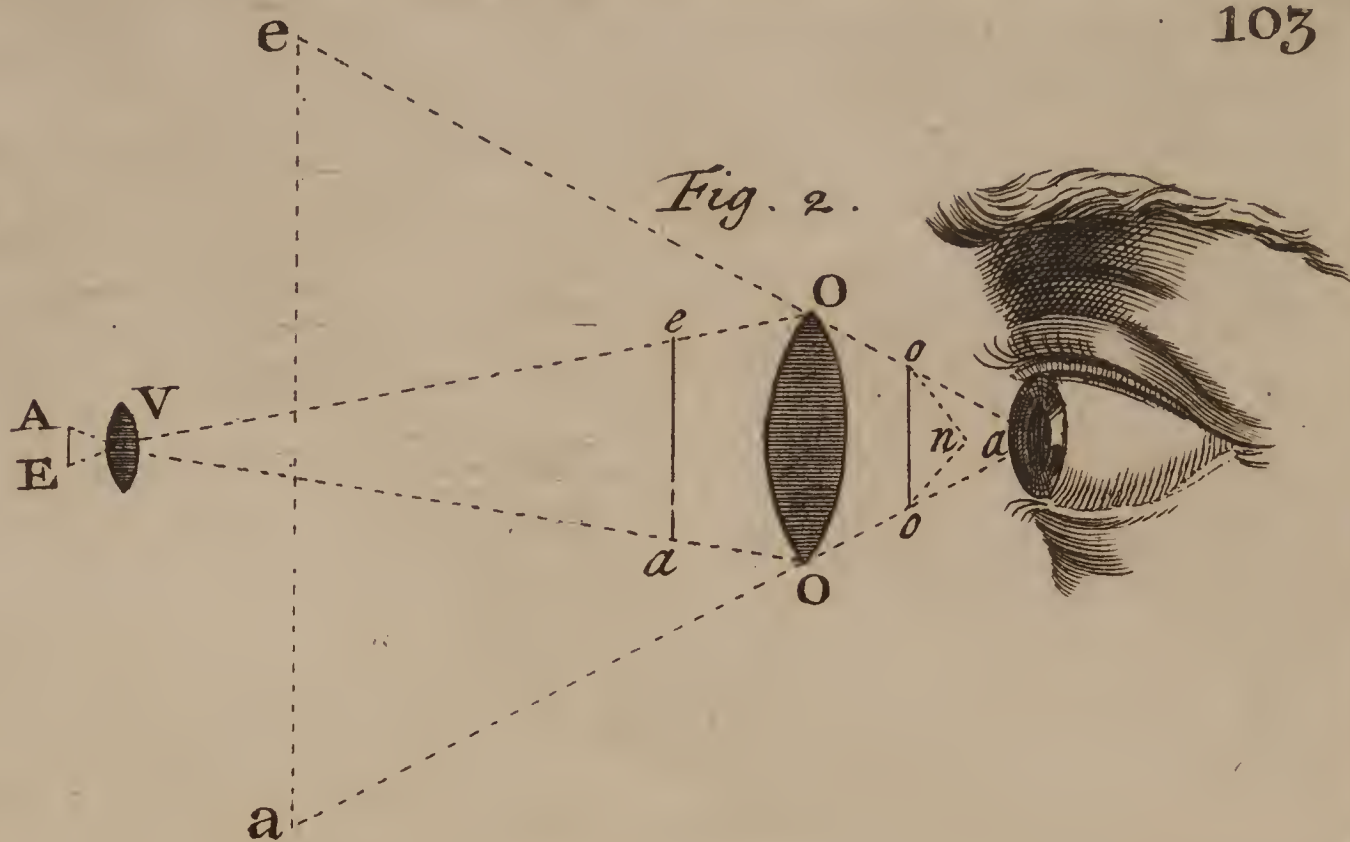


Fig. 6.

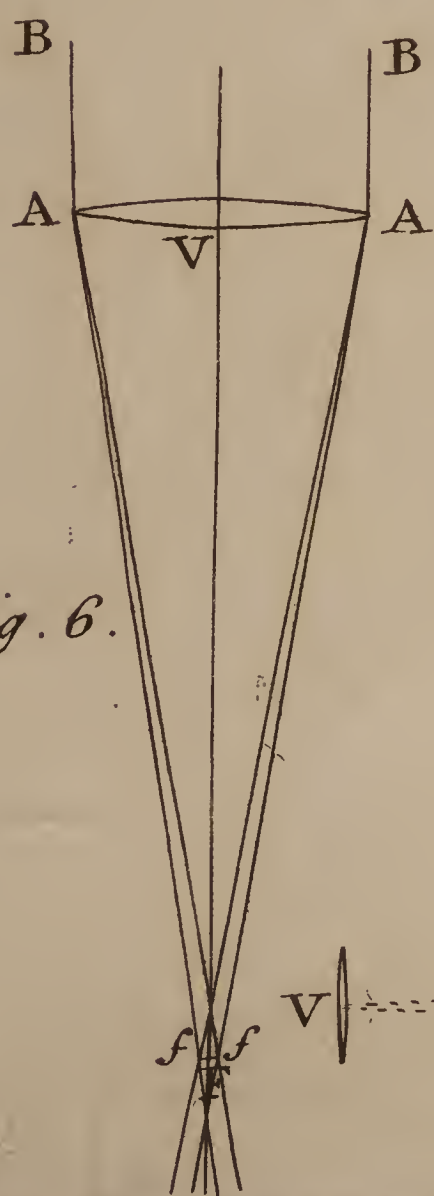


Fig. 5.

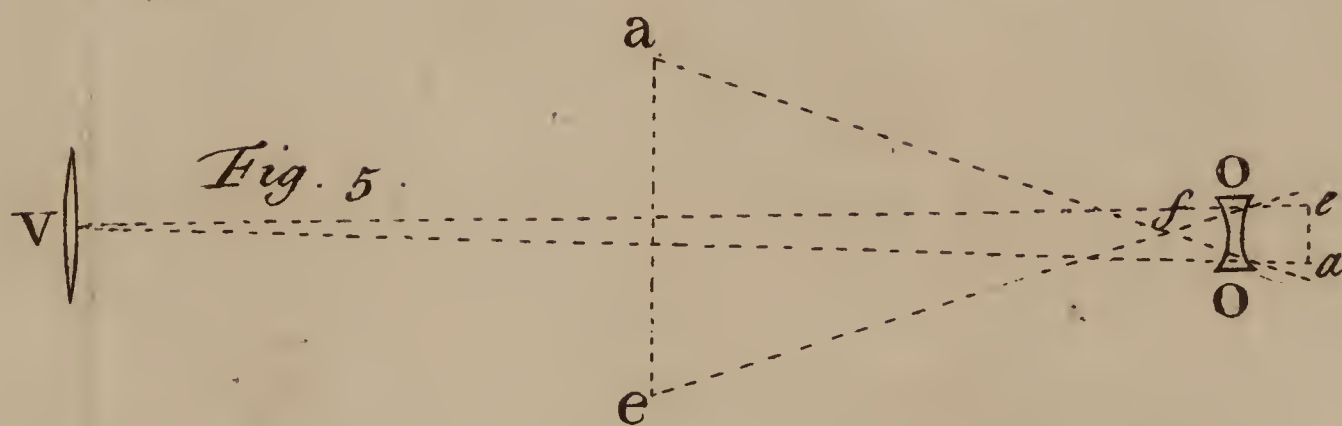


Fig. 3.

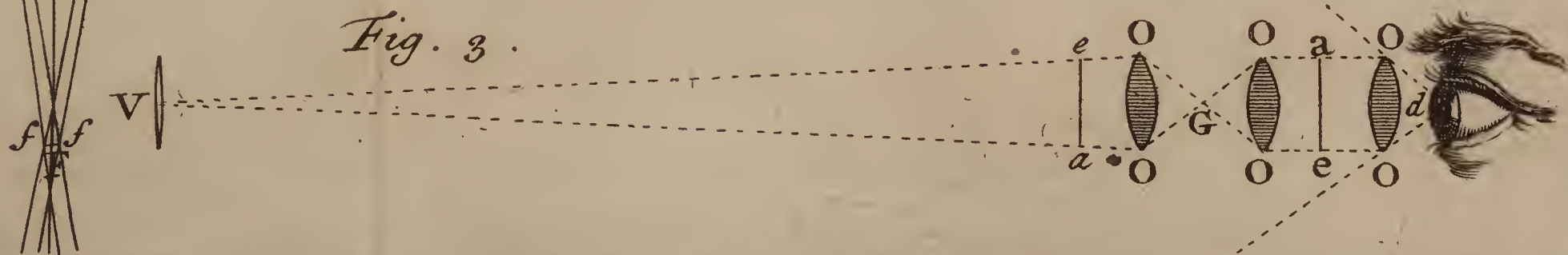
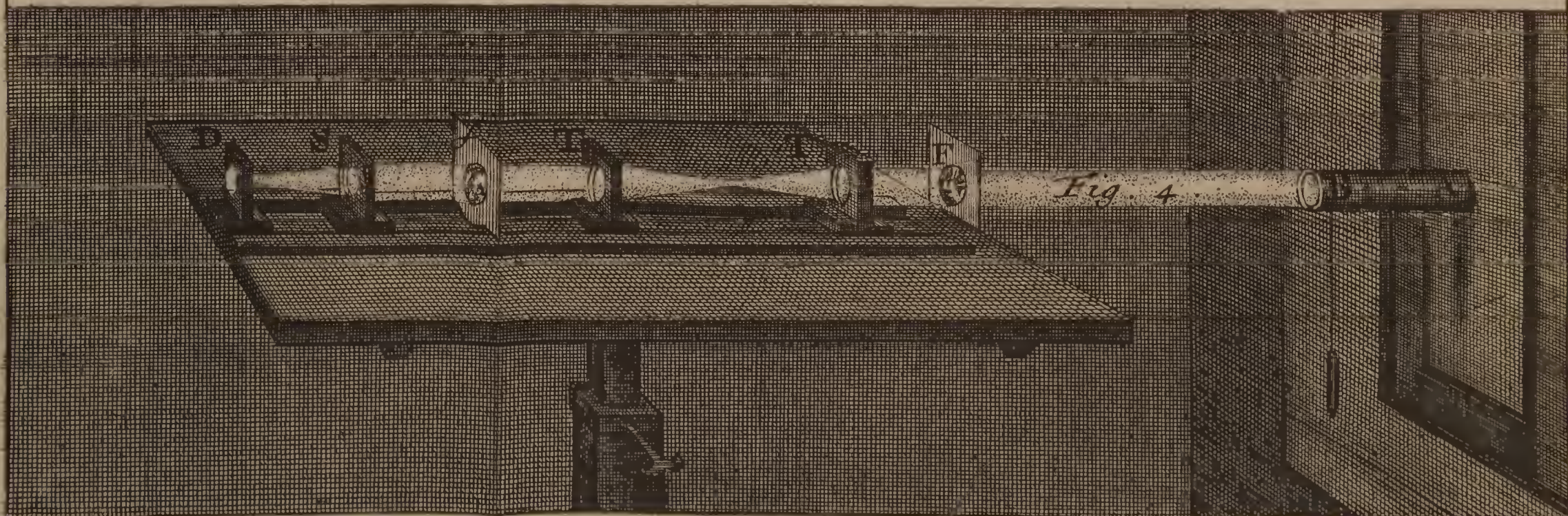


Fig. 4.



EXPERIMENT I.

Let there be in the Dark the plane Mirror S, which is supported 3242.
by a Stand in such Manner, that it may be plac'd as you please * ; Plate 104.
through a Hole in the metallic Plate L, which is fix'd in a Win- Fig. 2.
dow, a Ray of the Sun, of the Diameter of about a Quarter of an * 2735.
Inch, is let into a Chamber ; the Mirror is so plac'd, that the Ray
may pass through a cylindric oblique Cavity, (whose Diameter is
equal to that of the Ray,) in the Board T : If this be transpos'd,
the reflected Ray will pass through the same Cavity. This holds
good whatever the Inclination of the Cavity be, as may be demon-
strated by using different Boards.

By which Experiment is also manifest, what was said in N. 3235, 3243.
of the Surfaces of Bodies.

*If the reflected Ray becomes the incident Ray ; that is, if the Light 3244.
comes along the Line BC, it will return in the Line CA, that is, Plate 104.
the first that was the incident Ray will become the reflected Ray ; as Fig. 1.
appears from the Equality of the Angles BCO, OCA.*

From this Equality of the Angles of Incidence and Reflexion,
we farther deduce, that *the Light, after it has fallen upon a Body, 3245.
recedes from it with the same Force that it came upon it.* Let the Mo-
tion along AC be resolved into two Motions along AO and OC *, * 1155.
supposing AO parallel to the reflecting Plane, and OC perpendicular
to it. Let AO be continued ; the Motion in that Direction is not
alter'd from the Action of the Plane : therefore let AO and OB
be equal ; if the Light recedes from the Plane with the same Force,
with which it came upon it, the Motion occasion'd by the Repul-
sion is represented by CO, and in that Case the reflected Ray goes
through B * ; that is, the Angle OCB is equal to the Angle OCA, * 360.
which agrees with the Experiment.

As to the Reflexion of Light, it is to be observ'd, that *Light 3246.
does not run against the solid Part of Bodies, when it is reflected by
them ; but that it is reflected in those Places, where it could very freely
pass.* I shall prove this by several Experiments, by which many
other wonderful Properties of Reflexion are discover'd.

It is a common Experiment observ'd by every Body, that when
*Light is mov'd through any Medium ; as for Example, Glafs, 3247.
Water, or Air, it does not undergo a sensible and regular Reflexion ;
but that it is reflected there, where two Mediums of different Density
are separated ; so it is reflected in the Surface of Water or Glafs.*

Can Light in such Quantity strike against the Particles of the Mediums just where they are separated, where as it moves along both the Mediums for a great Space, without striking against any such Particles? Is there a greater Number of such Particles near the Surface than elsewhere?

3248. *Light also is more abundantly reflected in a more refracting Medium, when it comes against the Surface of a less refracting one; than when on the contrary, moving in a less refracting Medium, it strikes against the Surface of a more refracting one.*

EXPERIMENT 2.

3249. We make use of the triangular Glass Prism as A B, whose Bases
Pl. 104. are strengthen'd with Copper Plates to which Points cohere, that
Fig. 3. the Prism may be turn'd about it's Axis.

3250. We put the Axes into Incisions in the Edges of the smaller Sides
Pl. 104. of the Box E F. The Light enters through an Hole in the Plate
Fig. 4. L into a dark Place, and goes into the Prism; if the Light in the Prism makes the Angle of Incidence greater than 40 Degrees, it is wholly reflected, and none of it goes into the Air; but the Light in the Air is never wholly reflected by the Glass.

3251. But if the Reflexion be made by the striking of Light against the solid Parts of Bodies, there must be more such Parts in Air than in Glass; for if Light was reflected from the Glass itself into the Air, the Light would never come to the Separation of the Mediums; that the Light can also go out of Glass in the very Places, where it is reflected, is prov'd by the following Experiments. Therefore near the Glass there must be so many Parts in the Air, that there may be no Way for the Passage of the Light to cause it to be wholly reflected into the Glass: yet it does appear that there are not such; because the Light came to the Glass through the Air in all Directions, and enter'd into it. Also in the same Part of the Surface, separating the Glass and Air, the Light coming from one Side is reflected, whilst that, which came from the opposite Side is transmitted. Which clearly proves that the Light is there reflected, where it can pass through.

EXPERIMENT 3.

3252. The same Things being given, which were in the foregoing Ex-
Plate 104. periment, if the Obliquity of the Light be diminish'd, this will in
Fig. 4. part pass into the Air.

Who can conceive that the Light, which passes out of the Glass into the Air, and does not strike against solid Parts, should, if the Obliquity be a little increased, all of it strike against such Parts;

since in each Medium there is a Passage for it in every Direction, as has been said ?

EXPERIMENT 4.

The Prism being plac'd, as in the last Experiment; turn it slowly, 'till it reflects all the Light, as in the second Experiment *; then the Angle of Incidence of the Light, falling upon the lower Surface of the Prism, is about 40 Degrees. The Prism must be fix'd in this Position by Means of the Screw C. Now if Water be pour'd into the Box, at the Moment, when the Water touches the Glass, the Light enters into it in great Plenty. 3253. Plate 104. Fig. 4. 3249.

The Experiment answers in the same manner, though the said Angle of Incidence exceeds 40 Degrees. So that it does not exceed 60 Degrees. But it is the more sensible, the smaller this Angle betwixt the said Limits is.

This Experiment does not agree with the Reflexion, arising from the striking against the solid Parts.

In the following Part of this Book we shall also see, that thin Plates, which reflect Light, do transmit it, if they become thicker. 3254.

This Experiment also proves, that *the reflecting Force is the greater, the greater the Refraction in the reflecting Surface is*; for Glass and Air differ more in their refracting Force, than Glass and Water do. 3255.

From this Experiment we also deduce, that *the Reflexion is made from the same Force, by which the Rays are refracted; which in different Circumstances produces different Effects.* 3256.

A Ray, which passes out of a more refracting Medium into a less refracting one, recedes from the Perpendicular by Means of the Attraction of that Medium *; if the Obliquity of the incident Ray be increased, the Obliquity of the refracted Ray is increased also, 'till at last this moves in the Surface itself, that separates the Mediums. Which obtains, when the Sine of the Angle of Incidence is to the whole Sine, as the Sine of Incidence, in the first Medium, is to the Sine of Refraction in the second; for in this Case the Angle of Refraction is a Right one. If the Obliquity of the incident Ray be further increased, it is manifest that the Ray cannot penetrate into the less refracting Medium; this is the Case, in which all the Light is reflected; which Reflexion depends upon the Attraction with which the Rays are refracted. 3257. 2782.

Let EF be the Surface separating the more refracting Medium X from the less refracting one Z; let us suppose the Space of Attraction * to be terminated by the Surfaces GH, IL; if a Ray, as AB, * 2806. Plate 104. Fig. 5.

be sufficiently bent by the Attraction of the Medium X, so that, before it shall have passed through the whole Space of Attraction, the Tangent to the Curve be parallel to the Surface separating the Mediums, the Curve being continued goes back; and therefore the Ray is reflected along CD, from the Attraction of the Medium, whose Action upon the Light overcomes the opposite one. This Continuation of the Curve is similar, and equal to the first Portion, and makes the Angle of Reflexion equal to the Angle of Incidence; because the Light returns along the same Part of the Space of Attraction, and the same attracting Forces act upon the Light in corresponding Points of the Portions of the Curve. Thus a Body projected, describes similar and equal Curves, in it's Ascent and Descent.

Now as the Reflexion of the Light, in this Case, is plainly to be attributed to the Cause of Refraction, who can imagine, when the Inclination is diminished, so that the Ray in part passes through,
 * 10. that another Cause is to be sought *?

3258. Nevertheless it is manifest that *all Reflexion does not depend upon this Attraction in the same manner*; for in that Case in which the Refraction is given, the Light is in part reflected; the Light does not indeed wholly pass out of the less refracting into the more refracting Medium; for in this Case also, in which the Attraction is most opposed to the Reflexion, some Rays are reflected; which Effect must be attributed to the Repulsion, which we have also
 * 2726. found to act where there is Attraction *.

3259. From all this it follows that the *Reflexion in every Case, has a Relation to the refracting Force*.

3260. Therefore *where Light passes without Refraction, there it is not reflected* *; but *where the Refraction is greatest, there also the Reflexion is stronger* †; the Light being supposed in the Air, the Surface of the Glass reflects more strongly, than that of the Water; and the Surface of Diamond still stronger. The Glass and Diamond being immersed in Water, in the Separation of these Bodies by the Water the refracting Force is less, than the Air, and of the same Bodies: These Bodies also reflect Light less strongly in Water, than in Air. If Light moves in Glass, and strikes against the Surface of Air, it is all reflected at a less Obliquity, than when it strikes against
 * 3247. the Surface of Water *.
 † 3255.

From what has been hitherto explained concerning Reflexion we infer, that it is not made in the Surface of Bodies; but that
 3261. *Light is reflected at a certain Distance from Bodies, in the same*

manner as the refracting Force acts at a certain Distance from a Body; which Proposition we can also deduce from the Reflexion of Light from Surfaces made smooth by Art; for it has been observ'd, that *Bodies, that are made smooth by Art, reflect Light regularly,* though there are innumerable Scratches in their Surfaces: For they are polish'd by the rubbing of Powders, and how small soever these Particles are, they leave large Scratches on the Surface with regard to Light; whence the Reflexion in the Surface must necessarily be irregular; but if we conceive the Reflexion to be made at a small Distance from the Surface, the Irregularities are diminish'd, and almost wholly taken away; as is easily perceiv'd if we consider the Matter.

3262.

C H A P. XIV.

Of plane Mirrors.

LET bc be the Surface of a plane Mirror; R the Radiant Point. Let the Plane of the Mirror be continued, and let down to it the Perpendicular RC from the Radiant R ; if this be continued, and Cr be equal to CR , r will be the Point of Dispersion of the reflected Rays coming from R . 3263. Plate 104. Fig. 6.

Let Rb be the incident Ray; bf the reflected Ray; let this be continued beyond the Speculum; by reason of the Angles of Incidence and Reflexion being equal to one another *, the Angles RbC , fbC , their Complements are also equal; to this the opposite vertical Angle rbC is equal †: The right angled Triangles RbC , rbC have the common Side Cb , and the Angles Cbr , CbR equal; therefore they agree in every Thing, and CR and Cr are equal to one another *; which Demonstration may be applied to all other Rays, proceeding from R , in what Plane soever perpendicular to the Plane of the Mirror, they be conceiv'd. Therefore wheresoever a Spectator be, if the reflected Rays come to him, they will enter his Eyes, as if they came from r ; and the Point R will appear in this Point †; but the Appearance of this Point has the same Position with regard to the Mirror, behind it, which the Radiant Point itself has before it. 3264. 3241. † 15. El. 1. * 26. El. 1. 3265. 3122.

Which if it be applied to all Points of the Object, it will appear, that the Object appears behind the Mirror in that Position, which it really has before it. 3266.

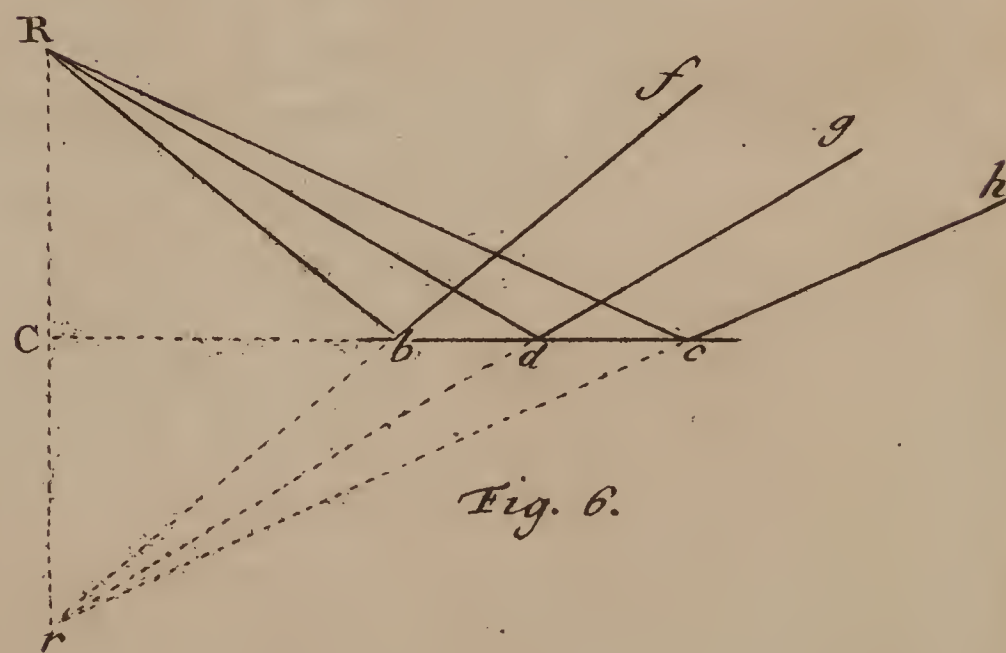
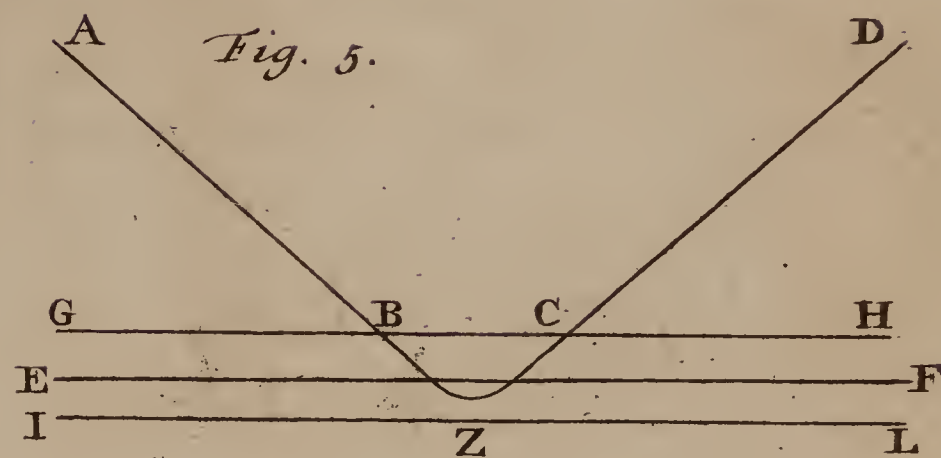
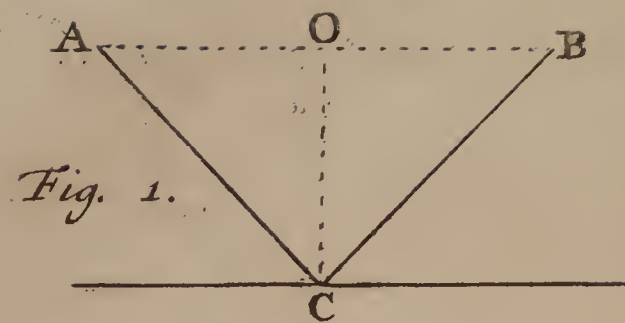
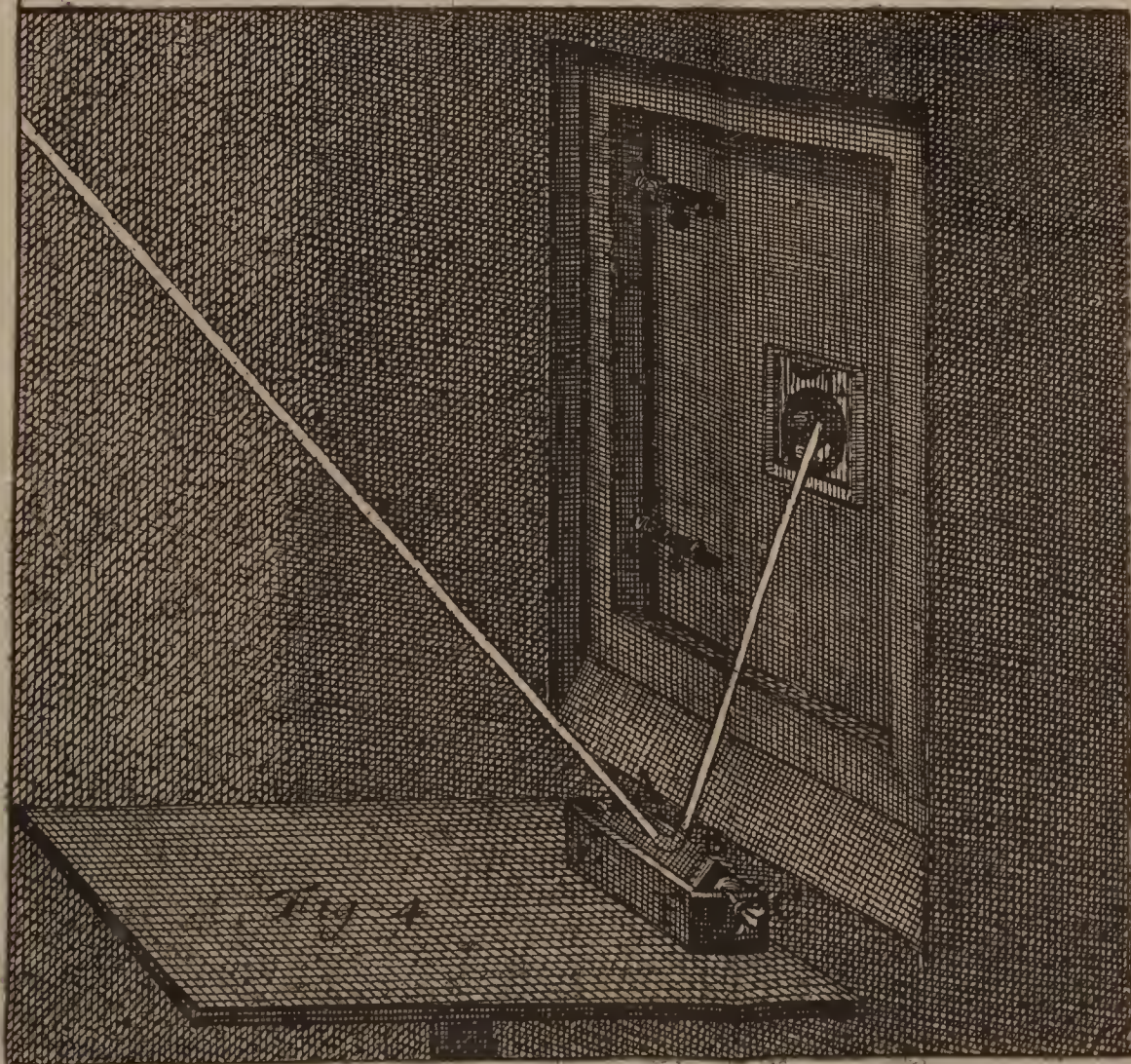
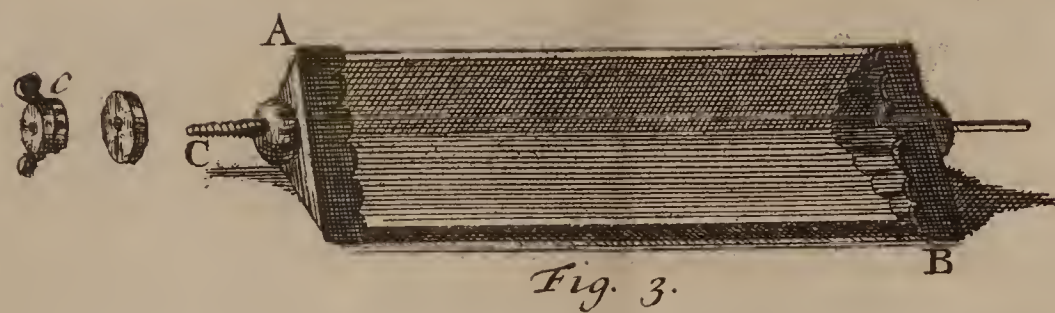
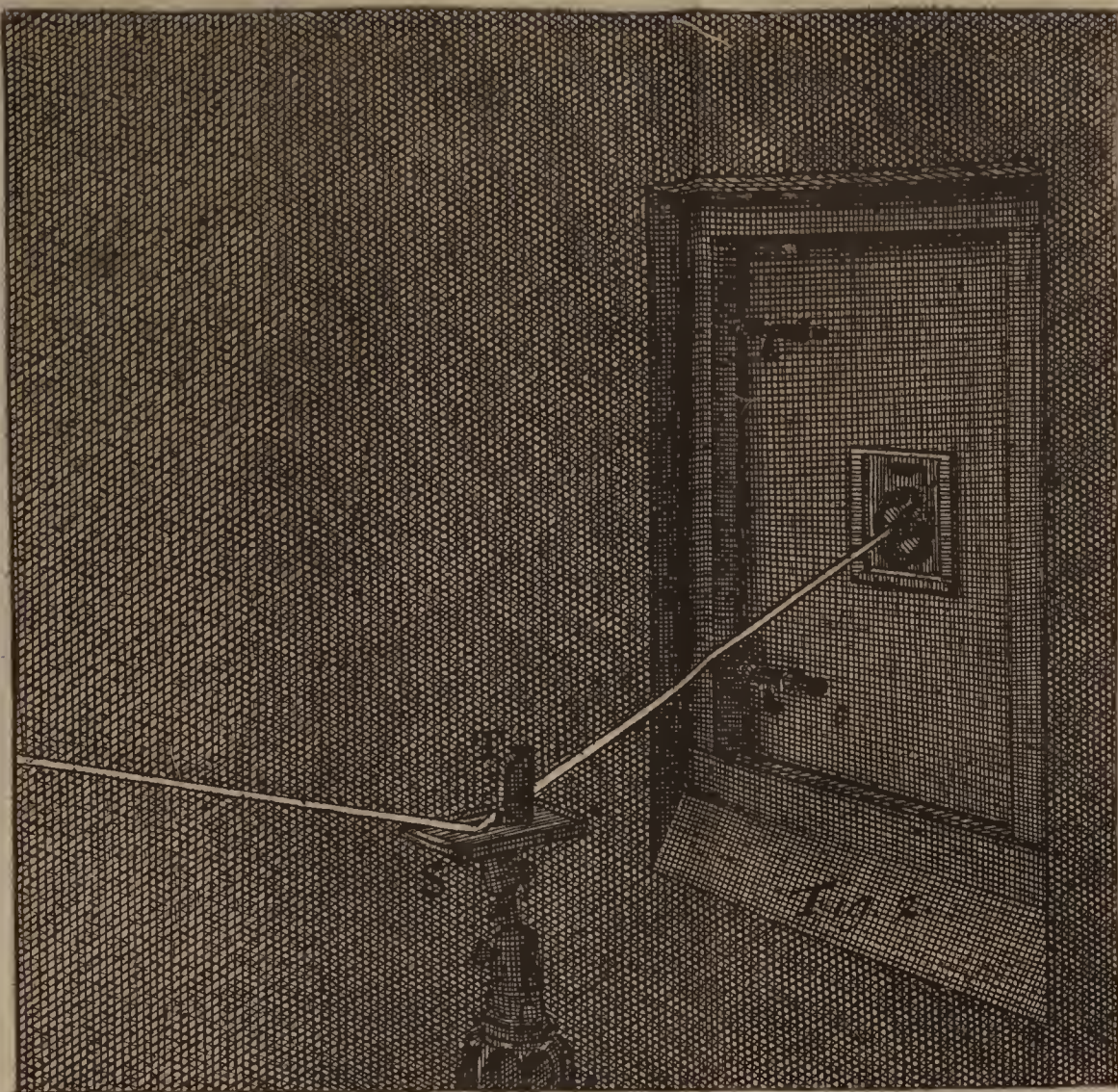
If

3267. If there be many Mirrors, and the Light reflected from one, strikes against another, in order to discover the Place in which the Object appears, we have the Image in the first Mirror for an Object with regard to the second, and so of the others. This Rule alone is sufficient to explain all the Phenomena of plain Mirrors, howsoever combin'd.

C H A P. XV.

Of convex spherical Mirrors.

3268. **E**VERY spherical Surface may be considered as made up of
 * 2917. innumerable small Planes *; and a Plane touching the Sphere in any Point, is, as it were, a Continuation of such a small Plane.
3269. Spherical Mirrors are either *concave*, or *convex*.
 The former are made of a concave polished Portion of a Sphere. And the latter of parts of Spheres polished on the outside.
3270. *A Ray striking upon any spherical Mirror, together with it's reflected Ray, is in the same Plane, which Plane being continued, passes*
 * 3239. *through the Center of the Sphere **, for such a Plane is perpendicular to the Surface of the Sphere.
3271. *A Line which is drawn through the Center of the Sphere and Point of Incidence, being continued, makes equal Angles with the incident and*
 * 3241. *reflected Rays **, for this is perpendicular to the Surface, and these
 3272. are the Angles of Incidence and Reflexion: Therefore *the Ray which passes through the Center, or which being continued would pass through the Center, when reflected, returns upon it self.*
3273. Let R be the radiant Point; *G a G* is the convex Speculum;
 Plate 105. C the Center of the Sphere; and *G D* a part of a Section of the
 Fig. 1. Sphere continued: Let *R a*, *R b*, *R c*, *R d*, be incident Rays,
 * 3272. when reflected they will be *a R*, *b n*, *c m*, *d l **.
3274. *If from the Radiant Point R, a Tangent be drawn to the Mirror, the reflected Ray will be the Continuation of the incident Ray, or rather the Reflexion of the Rays is terminated in the Point of Contact.*
3275. *If the Rays l d, i m, n b, R a, which are reflected from the convex Mirror, be continued out, with all the intermediate ones, their Intersections will form the Curve F G, which all those Rays touch, and the adjacent Rays intersect one another in the Circumference of the Curve itself; so that they always enter the Eye as if they came from some Point of the Periphery; in which therefore the Image of the*
 Point



Chap. 15. of Natural Philosophy.

207

Point does always appear *, as long as the reflected Rays can come *
to the Eye, and the Eye be moved in the Plane going through the
Center of the Sphere. But when the Eye is removed out of that Plane,
the radiant Point appears in some other Curve, because there are such
Curves in every Plane, which may be conceiv'd to pass through the
Line R C. 3122.
3276.

If the Eye be in the Line dl , the Point f of the Curve, from
which the Rays seem to proceed, is determin'd by this Proportion:
The incident Ray Rd is continued to D ; the Point e is mark'd in
such manner that de may be equal to a Quarter of the Cord dD ;
and Re is to Rd , as de is to df . Which we shall demonstrate in
the following Scholium. 3277.

In the same Scholium we shall also consider the Thing more ac-
curately, and we shall see that all, which we have delivered con-
cerning the Translation of visible Points through the Curves men-
tioned, as likewise that which I shall presently add, belongs to other
Curves; but as the Consideration of these second Curves is intricate,
and as our Mind rarely refers the Point itself of the Object to the
visible Point *, it is sufficient to consider the first Curves, upon *
which the second depend, as will be seen in the said Scholium. 3278.
3124.

If the Rays be direct, that is, if Ra be given amongst them,
which being continued would pass through C , RE and RF are
in the same Line *, and aF is less than aE which is equal to a *
Quarter of the Diameter. 3279.
3272.

The Point F coincides with E when R is remov'd in infinitum; for
then Ra , RE , must be look'd upon as equal. 3280.

The Point F is, of all the Points of the Curve, the most distant from
the Surface of the Speculum. 3281.

Now any radiant Points being given, all the Curves of these
Points, and indeed the whole Curves are within the Sphere; and
therefore all the Objects appear behind the Surface of the Speculum. 3282.

If the Point R be mov'd about the Speculum, the whole Curve
 $GF G$ is carried with the same Motion; therefore as the Radiant
ascends, the Representation ascends also, and the contrary; and the
Objects appear erect. 3283.
3284.

How great soever the Space taken up by the Objects be, the Ap-
pearances are inclosed in a strait Line *. Whence it follows that *
the Objects appear diminished. 3280.
3285.

If the Eye be mov'd, the Appearance of the Object is also mov'd,
and it's Figure chang'd: For all the Points are mov'd in their own
Curves, and that unequally, according to the different Situation of
the 3286.

the Eye in respect of each Curve ; whence of Necessity the Figure must be chang'd.

EXPERIMENT.

3287. If any one sees his Face in a spherical convex Mirror, stand-
 Plate 105. ing at A, he will see his Face erect at a , diminish'd and unlike;
 Fig. 2. by the Motion of the Eye one may observe the other things men-
 tioned, in respect to fix'd Objects.

SCHOLIUM I.

The Demonstration of the Rule deliver'd in N. 3277, whereby the Appearance of a Point is determin'd.

3288. LET there be the incident Rays RA, Ra , which we conceive to be
 Pl. 105.F.3. continued, as far as D, d ; and AD is $= 4 AE$. And let there be
 the reflected Rays AI, ai , which being continued backwards to AB, ab ,
 mutually intersect one another at F . The Angle ARa being supposed
 very small, F is sought.

* 36. El. 3. $RA, Ra :: Rd, RD$ *.

16. El. 6. Therefore the Triangles RAa, RDd are similar $\dagger$; and

$\dagger$ 16. El. 6. $Dd, Aa :: RD, Ra$ or RA ;

for these are taken as equal, by reason of the small Angle DRd .

3289. By Compos. $Dd \dagger Aa, Aa :: RD \dagger RA, RA$.

* 35. El. 3. In the same manner $FA, Fa :: Fb, FB$ *;

16. El. 6. And the Triangles FAa, FBb are similar $\dagger$; and

$\dagger$ 15. El. 1. $Bb, Aa :: FB, Fa$ or FA .

6. El. 6. By Divis. $Bb - Aa, Aa :: FB - FA, FA$.

3290. By reason that the Angles of Reflexion are equal to the Angles of

3291. Incidence *, DAC, BAC are also equal, as also dac and bac $\dagger$;

* 3271. wherefore the Chords AD, AB , and ad, ab are equal; therefore

$\dagger$ 15. El. 1. $AD - ad = AB - ab$; that is, $Aa \dagger Dd = Bb - Aa$; and the first

* 3289, 3290. Ratios of the Proportions deliver'd above * agree.

Therefore $RD \dagger RA, RA :: FB - FA, FA$.

By Compos. $RD \dagger 2RA, RA :: FB, FA$.

By Comp. and Altern. $RD \dagger 3RA, AB :: RA, FA$.

But $RD \dagger 3RA = 4RA - 4AE = 4RE$, and $AB = AD = 4AE$;

Therefore $4RE, 4AE :: RE, AE :: RA, FA$.

According to the Rule, which is deliver'd in the said N. 3277.

3292. If we conceive the Lines RA, Ra to revolve about RC , the Angles
 ARC, aRC remaining, the Point F will describe a Circle; and it is ma-
 nifest that only those Rays, which are in the Plane of the Figure, meet
 at F : If, therefore, the Rays proceeding from R make a Cone or Pyra-
 mid, the Rays, how little soever dispersed, don't meet in one Point, but
 by

by mutual Intersections make a small Portion of the said Circle, namely a small Line perpendicular to the Plane of the Figure at F. The same Rays also pass all along the small Line L l, so that what obtain'd in the refracted Rays*, takes Place here, in the imaginary Intersections of the Rays * 2901. 2987. produc'd backwards. Whence it follows, if we consider the Thing accurately, that the Point F is not a visible Point*; but that the square* 3122. Spot is to be look'd upon as such, as has been mention'd above†. The † 290. Place Q of this Spot, if we consider the Rays, which go directly through the Pupil into the Eye, is determin'd, if in the Line A L, in which the Point F is now given, the Point Q be determin'd in such manner, that the Line may be divided harmonically; that is, that $LA, LQ :: AF, FQ$. A P being drawn through A, parallel to R C; draw through P, taken at Pleasure P F, which cuts R C at S; L S being divided into equal Parts at s, the Line P s will determine the Point Q.

But all this is of no Use in explaining Phenomena*. Therefore it is sufficient to have explain'd what relates to the Curves, passing through Points as F, neglecting the second Curves, which pass through Points as Q; this we know, that the Appearances are chang'd with the Points, as F and Q, which are always chang'd together: For which reason, in the following Chapter I shall only consider the first Curves.

When incident Rays, a little dispersed, are direct, that is, if among these there be a Ray, which continued would pass through C, the Points F, Q, and L coincide. 3294.

C H A P. XVI.

Of spherical concave Mirrors.

WHEN we consider Objects, seen by Rays reflected from a Mirror, it is needless to treat separately of direct and oblique Rays; because, whilst some few Points of an Object are seen by direct Rays, all the rest are seen by oblique Rays. For this reason in the last Chapter I did not treat separately of direct Rays; but as other Phenomena also are to be explain'd in this Chapter, which depend upon direct Rays, I shall treat of these first. 3295.

Let there be a concave Speculum B D, C is the Center of the Sphere; let direct parallel Rays fall upon the Surface of the Mirror, among which is C D passing through the Center; by Reflexion Fig. 4. this returns upon itself*, and the neighbouring Rays, being reflected* 3272. converge, and meet with it at the Focus F, the middle Point betwixt D and C. 3296. Plate 105.

3297. Let AB be a Ray at a small Distance from CD , draw the Semi-diameter CB ; the Angle of Incidence will be ABC , to which
 * 3271. the Angle of Reflexion CBF is equal *, as also the alternate An-
 † 29. El. I. gle BCF †; therefore BFC is an Iſosceles Triangle, and the
 ‡ 6. El. I. Sides FC and FB are equal ‡. By reason of the ſmall Arch BD ,
 FD and FB do not ſenſibly differ; therefore FC and FD are equal:
 Which Demonſtration agrees to all the Rays at a ſmall Distance from CD .
3298. If the parallel Rays be at a greater Distance from CD , they will not meet at F ; but they all meet in a ſmall Circle, whoſe Diameter depends upon the Magnitude of the Mirror.
3299. The Rays which come from any Point of the Sun, fall parallel
 Plate 106. upon the Mirror; and if they be a little diſpers'd, they meet in a
 Fig. 7. Point in that Ray, which paſſes through the Center of the Sphere. If DA and EB be Rays proceeding from the Extremities of the Diameter of the Sun, theſe being reflected meet at a and b with all the others, proceeding from the ſame Points of the Sun, and reflected from the Mirror. If theſe fall upon a Plane, they will give the Images of the ſaid Points at a and b , and we have the Image of the whole Sun in the ſame manner, and the Line ab is the Representation of the Diameter.
- As in this Image, a great Plenty of the Sun's Rays is collected
 * 3051. in a ſmall Space, we have the ſame Effect as in *Burning Glaſſes* *;
 3300. and concave Mirrors are *Burning Glaſſes*, which *for the moſt part burn Bodies more violently than Glaſſes*; becauſe they may eaſily exceed Glaſſes in Magnitude.
3301. When the Diameter of a Mirror is ſmall, for Example, not exceeding ſix Degrees, the Image of the Sun is diſtinct, and all the Rays, reflected from the Speculum, paſs through it; then the ſmall Line ab , which is the Diameter of the Place, where the Combution is, is leſs than the hundredth part of the Distance Aa , or Bb , as will be ſeen in the firſt Scholium following.
3302. If the Mirror be enlarg'd, the Image becomes imperfect, and by this the Diameter of it is increaſed; but the Effect of the Mirror is increaſed by this Dilatation, becauſe the Number of Rays paſſing
 3303. between a and b is increaſed. But it is needleſs to increaſe the Mirror in ſuch manner, that the Arch LM , which determines the Diameter of the Mirror, may exceed five Degrees; for the Mirror being ſo order'd, that ab may anſwer to the Center of it, none of thoſe Rays, which would ſtrike againſt the Mirror beyond M and L can come to the Image a, b , and increaſe the Effect of the Mirror,
 if

if the Diameter of the Mirror should exceed the said Measure of twenty five Degrees.

EXPERIMENT I.

Let there be a concave Speculum S made of Metal, or Glafs, that has Quickfilver upon the back part of it. This is supported by two Pillars A B, A B, between which it is inclined as you please, these are in a transverse piece of Wood *aa*, which is put upon the Stand P, and is moveable about an Axis going into the Stand itself. 3304. Plate 105. Fig. 5.

The Mirror is exposed to the Sun Rays in such manner that the Rays which come to the middle Point of the Mirror may be perpendicular to the Surface of it; as all the other are parallel to this, they are collected in the Image of the Sun, at a Distance from the Mirror equal to a Quarter of the Diameter of the Sphere, and there burn violently.

If the Diameter of the Surface of the Mirror be as in mine, about fifteen Inches, and the Focus be at the Distance of a Foot and half, Wood is immediately set on Fire, and thin Plates of Lead are melted in a short Time.

If two such Mirrors be placed vertically, in such manner, that the Line, which passes through the Centers of both, may pass through the Center of the Spheres, we may extend the Action of a burning Coal to a great Distance. 3305.

Let the Distance between the Mirror be twenty Feet, and a Burning Glafs plac'd in the Focus of parallel Rays in the said Line, let Gunpowder be placed in the Focus of the other Mirror in the same Line; if you make the Coal burn fiercer with a Pair of Bellows, the Gunpowder will be set on Fire; for by the second Reflexion the Rays are collected, which after the first are parallel. For when the Focus, in which the parallel Rays are collected by the concave Speculum, becomes the radiant Point, the Rays being a little dispersed, are reflected parallel to one another *. 3306. * 3296. 3244.

What has been said † concerning parallel Rays a little dispersed, and direct, may also be apply'd to oblique Rays. For if there be Rays D A, *da*, these being reflected mutually, intersect one another at F in such manner, that A F may be equal to a Quarter of the Cord A B; which follows from the Proposition which will be presently deliver'd *, and demonstrated in the following Scholium. 3307. Plate 105. Fig. 6. † 3296. * 3315.

Hence we deduce a Method of representing Objects in a dark Place, like that mention'd before, by making use of a convex Lense *. 3308. * 3058.

Plate 106. Let there be a Hole F in a Wall; let ab be a concave Speculum, so plac'd, that the Rays passing through F , and which are perpendicular to the Wall, may be direct, and if they are parallel, they may after Reflexion be collected in the Center of the Hole: The Rays which being reflected from Objects mutually intersect one another in this Center, are reflected perpendicular to the

* 3306. Wall *.

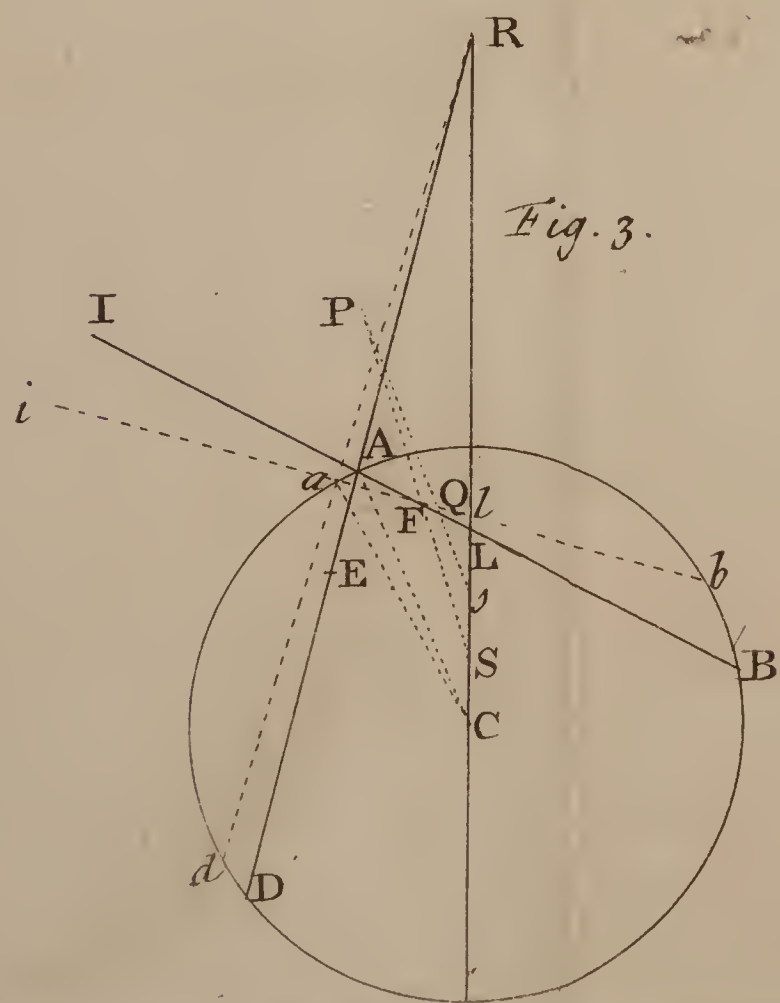
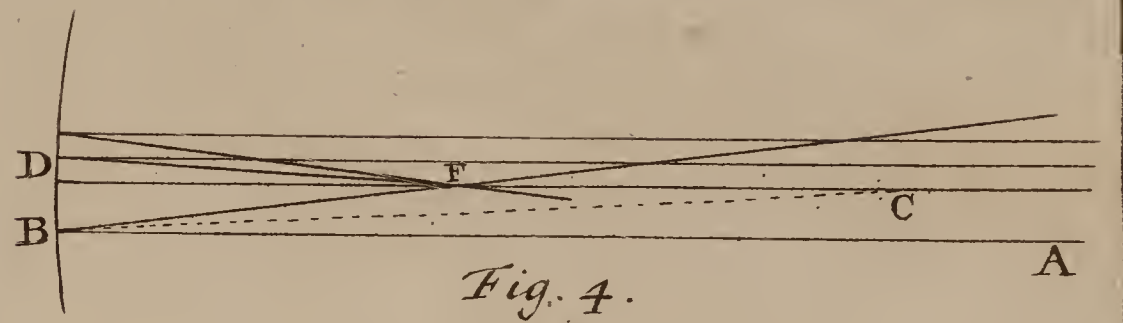
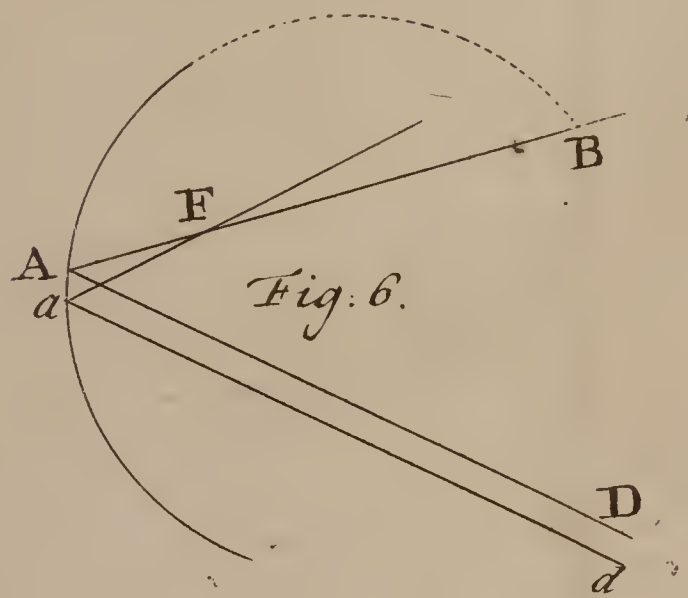
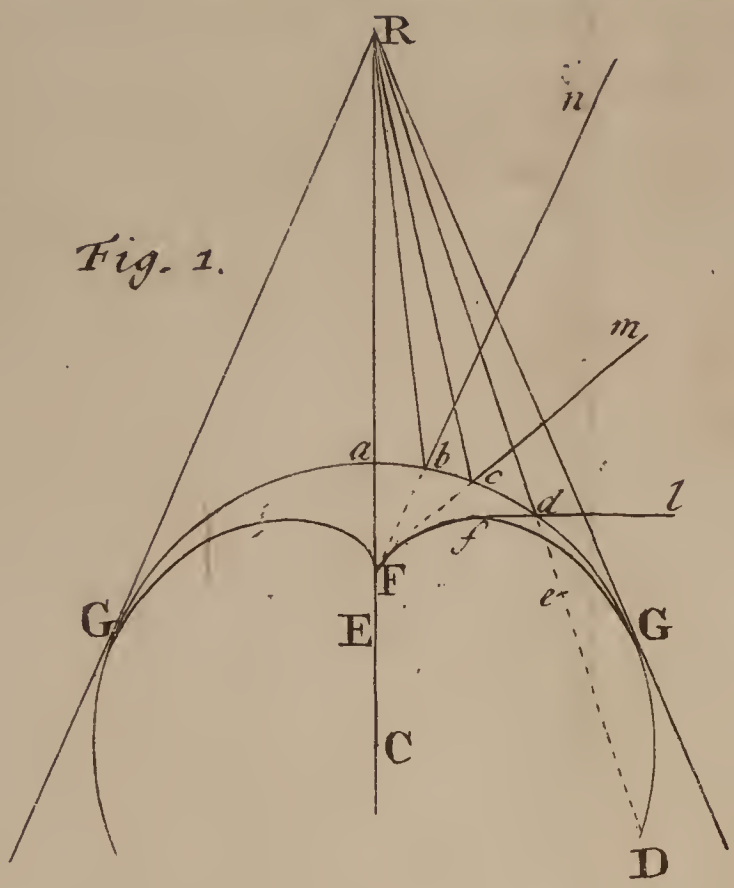
Let AF be Rays proceeding from a Point of a distant Object, which we look upon as parallel by reason of the Distance of the Point; among these, that which passes through the Center of the Hole is reflected from the Mirror perpendicular to the Wall *, and together with this the rest of the Rays proceeding from the same

* 3307. Point, are collected at a , where the Representation of the Point is *. In the same manner the Rays along BF proceeding from another Point, are collected at b ; which as it obtains in Respect to all the Points of the Object, they have all their Focusses; but all these Focusses, as far as can be perceived, fall upon the Surface itself of the Wall *, and there give the Picture of the Object.

EXPERIMENT 2.

3309. In a dark Place the Window is cover'd with the white Paper A
 Plate 106. in the Middle of which is the Hole F , whose Diameter is some-
 Fig. 2. what greater than half an Inch, and which agrees to the Hole in the Window, to which various Objects illuminated by the Sun answer at the Distance of at least fifty Feet; the concave Mirror S , the Diameter of whose Surface is fifteen Inches, and which collects parallel Rays at the Distance of eighteen Inches, is plac'd, at this Distance from the Window, in such manner that a Line, passing through the Center of the Hole, and the Center of the Surface of the Mirror, may be perpendicular to the Plane of the Paper and the Surface of the Mirror, then the Objects are represented above the Paper in a Circle concentrick with the Hole, and whose Diameter scarce differs from the Diameter of the Mirror. A hollow'd truncated Cone is join'd to the Hole without the Chamber, to include the Light which does not come from the Objects to be represented *.

* 3060. 3310. Something like this we demonstrate with regard to near Objects.
 Plate 107. Let R be the Radiant Point, RCa a Ray running directly against
 Fig. 1. the concave Mirror LM , the Center of whose Sphere is C ; this is reflected along aC , and the neighbouring ones proceeding from R as Rb meet with it at f , which Point, as we demonstrate in the Scholium,



Scholium, is found by this Proportion: Let e be the Focus of parallel Rays *, as Re is to Ra , so is ae to af ; if f becomes the Radiant, R will be the Focus, which is found in the same manner; for from that Proportion we deduce this, fe is to fa as ae is to aR . If there be many radiant Points, every one will have it's Focus, and by Means of them an Object may be represented.

Let C be the Center of the concave Speculum ML and AB a lucid Body, which is at a less Distance from the Speculum than from the Center C , the Ray Ad , which is perpendicular to the Speculum, is reflected along $dACa$, and has it's Focus at a . We reason in the same manner concerning the other Points of the lucid Body, an inverse Image of which is made at ab .

EXPERIMENT 3.

The concave Speculum S being put into a vertical Position, let the Flame of a Candle be placed between the Center of the Sphere and the Focus of parallel Rays at F ; if direct Rays coming from the Flame, being reflected from the Speculum, fall directly upon the white Plane P , placed at a just Distance beyond the Center, the Picture of the Flame will be inverted.

The Distance of the Plane from the Speculum is the less, the greater the Distance of the Flame from the Speculum is *.

If the Surface of the Speculum be small, the Representation is accurate, that is circular; because the Rays that are a little dispersed are collected accurately enough. If this Surface be greater, the Representation of the Flame is surrounded with a kind of false Light, which is to be attributed to the more oblique Rays of which I shall now speak more distinctly, for the Appearances of Objects belong to these chiefly.

Let there be a concave Speculum ad ; C the Center of the Cavity; R the radiant Point, at a greater Distance from the Speculum than the Center C ; Ra , Rb , Rc , Rd , the incident Rays, of which the reflected Rays aC , bg , ch , di , by mutual Intersections with the intermediate ones, make the Curve Ffl , which they all touch; therefore the Point R appears in this Curve, and, the Eye being mov'd in the Plane of the Curve, the Appearance is transfer'd along this Curve, as has been said of convex Speculums *.

In the same manner also, as has been explained of convex Speculums, we discover the visible Points; if the Eye be in the Line di , along which the incident Ray Rd is reflected, which cuts the Sphere continued at D , de being taken equal to a Quarter

of the Cord Dd , RE will be to Rd , as de to df , as has been said
 * 3377. of a convex Speculum *.

But in every one of the Planes, which may be conceived to pass through CR , there is such a Curve; they all meet in the Line aCR , namely at F . Therefore *at the said Point F the reflected Rays are collected in the greatest Plenty; which therefore is call'd the Focus of Rays proceeding from R ; vice versa R is the Focus, the Radiant being supposed at F *, and these are the Points, spoken of above †.*
 * 3244.
 † 3310.

In this Figure the Part of the Curve which is one Side of the Line RC is only delineated; a like Part must be conceived on the other Side; both are joined in the Focus of the radiant Point.

3317. *As the radiant Point recedes, the Curve approaches the Speculum.*

As the Radiant approaches, the Curve recedes from the Speculum, and is mov'd toward the Radiant itself. Let R be the radiant Point, Plate 107. and DdD the Speculum, dfd is the Curve; and as the Radiant Fig. 4. approaches towards the Center C they are contracted; but *if the*

3318. *Radiant be in the Center itself, all the reflected Rays coincide with the*
 * 3272. *incident Rays* *; and the whole Curve as it were is collected in the Center.

3319. *If the Radiant approaches still nearer, so as to be between the Center and the Speculum, the Curve recedes more also, which then is beyond the Center; if DAD be the Speculum, dFd is the Curve, in which the Point F recedes most of all; in which all the Curves, which are conceiv'd in the different Planes, meet, and it is the Fo-*

3320. *cus of the radiant Point, which is at an infinite Distance, when the*
 Plate 107. *Distance of the Radiant from the Speculum is equal to a Quarter of*
 Fig. 5. *the Diameter of the Sphere* *, then the Curve is extended in infi-
 * 3297. 3306. *nitum, and the two Sides, which tend to the Focus of the radiant*
Point, are separated.

3321. *If the Radiant approaches nearer, the Sides, as dI , dI , mutually*
 Plate 107. *decline more from one another, because the Rays reflected from the*
 Fig. 6. *Part of the Speculum bAb diverge; that is, being reflected they mutually intersect one another continued beyond the Speculum, and make a new Curve behind the Speculum, which also consists of two Legs fl , fl , these meet in the Line CR continued, namely, at f ; and in receding from the Speculum are stretch'd out in infinitum.*

3322. On each Side of the radiant Point there is given in the Surface a Point as b , which separates the Rays making the Curves fl , dI , and the Ray Rb being reflected to bg touches neither Curve, if it be continued in infinitum, although it approaches to each Curve nearer and nearer.

This

Chap. 16. of Natural Philosophy.

215

This Point b may easily be determin'd if the Chord bB be drawn; Rb will be equal to a Quarter of it *, but this Part bR is a mean * Proportional between the Part RA of any other Chord, passing through R , and a third Part of the remaining Portion Ra of the same Chord †.

3323.
3307.

†35. El.3.

3324.

If the whole Sphere should be finish'd, with respect to the opposite Part of the Sphere, the Radiant would be at a Distance beyond the Center, and the reflected Rays would make the Curve dFd , mention'd before *, whose Legs dF , Fd , would join the separate Legs dI , dI .

* 3314.

In the second Scholium I shall speak farther of these Curves, and shall demonstrate what is only mention'd here; but now I shall briefly explain the Phænomena, which follow from what is said.

Objects plac'd beyond the Center are seen between the Speculum and the Center; for all the Points appear in the Curve as $F l$ *, *the Images of the Objects are also diminish'd and Inverted*: For they are reduced into a narrow Space; and in the Descent of the Point R the Representation of it ascends; for the Curve $F l$, keeps the same Position with Respect to RCa , which turns about the Center C .

3325.

Plate 106.

Fig. 5.

* 3314.

3326.

EXPERIMENT 4.

That the Representation of the Objects may not be less vivid by Means of the extraneous Light, the Speculum must be inclos'd in the Box. Let there be a Speculum, the Diameter of whose Surface is about eight Inches, and which is a Portion of a Sphere of the Diameter of one Foot and a half; let this be inclosed in the Box P , in whose fore Part there is a Hole of the Diameter of about five Inches, and from which the Speculum is distant three or four Inches; it is necessary that this Aperture be turn'd from the Light. Now if any one at A , beholds himself at the Distance of about two Feet from the Speculum, his Face will appear inverted in the Box, towards the Aperture; if the Spectator approaches, his Head will appear to be out of the Box.

3327.

Plate 106.

Fig. 6.

The Representation of a Point placed in the Center of the Sphere, coincides with the radiant Point itself, and is as it were swallowed up by it *.

3328.

* 3318.

If the Eye be plac'd in that Center, no Object will be seen by it; for those Rays only which come from the Eye are reflected to it *.

3329.

* 3272.

If

3330. If an Object be between the Center and the Point in which the parallel Rays that are reflected are collected, the Object also appears without the Mirror, at a greater Distance from the Mirror than the

* 3319. Object itself *; and it's Representation is inverted: Which is proved in the same manner as in N. 3326; and enlarged, because this is more distant from the Center than the Object is; for the Representation infinitely recedes from the Center, while the Object is moving through a fourth Part of the Diameter of the Sphere *.

3331. If the Object be less distant from the Mirror than a fourth Part of Plate 107. the Diameter of the Sphere, the Object will appear either before or Fig. 6. behind the Mirror, according as the Eye is placed. If the Eye be so placed, that the reflected Rays which form the Curve lfl , may come to it, it will see the Appearance of the Object magnified

* 3321. beyond the Mirror *; because the Curves, as lf , which belong to several Points, are diverging.

3332. If the Rays, which form the Leg dI , come to the Eye, the Object will appear without the Mirror; and in both Cases the Representation is erect; for as the Point A rises or falls, the Curves lf , dI , in which it is represented, are moved with the same Motion.

3333. If the Eye be in the Point, in which reflected Rays, reaching to different Parts of the Curve, mutually intersect one another, the Appearance of the Object may be double, or triple, as at O; but this cannot happen if the Mirror be made of too small a Portion of a Sphere.

3334. It easily appears in every Case, that the Points of the Appearance have not the same Relation to one another, which the Points of the Object have; and that therefore a concave Speculum never represents an Object exactly: But the Representation is very irregular, which is in the Lines, as dI .

3335. With regard to which it is to be observ'd, which must also be referr'd to lf , lf , that the visible Points are not in those Curves unless near the Points d , d , and f , because the Rays which belong to other Parts of these Curves and fill the Pupil, cannot be looked upon as Rays proceeding from one Point only.

3336. There are also cylindric, convex and concave Mirrors, as also conical convex ones; in one respect they are plane, in another spherical: Therefore the Representation of the Object is very irregular, which Irregularity, as it depends upon a regular Figure, may be determin'd in such manner, that Figures may be drawn, which being really irregular, seem regular, in such a Speculum, in a certain Position of the Eye.

S C H O-

SCHOLIUM I.

Of determining the Diameter of a burning Glass.

WHAT was explained in N. 3299, being given, the Angle DCE, 3337.
to which BCA is equal, determines the apparent Magnitude of Pl. 106.F.7.
the Diameter of the Sun, and is equal to about 32'. The Diameter ba
of the Image of the Sun is equal to half the Chord BA*, that is, it is * 3297.
equal to the Sine of the Arch 161, which, supposing the Radius AC =
100000, is equal to 465, and is to $Aa = 10000$, as 1 to 108; whence
appears what was said in N. 3301.

Rays parallel to the Ray CO, if they be at a small Distance from it, 3338.
being reflected pass along a ; if they be at a greater Distance they meet
with CA between A and a , as follows from what is before demon-
strated *. But those, which fall upon the Speculum between A and M, * 3297.
if they pass along the small Line ab , increase the Effect; but if the Arch
AM is equal to twelve Degrees, the Ray GM being reflected along
MH passes beyond b along i , and cannot assist the Combustion between
 a and b , as will appear from a Computation made.

Let MN, the Sine of an Angle of twelve Degrees, be 20791; NC 3339.
the Co-sine of the same Angle 97815.

MHC is an Isosceles Triangle *, therefore HI, which is perpendicu- * 3297.
lar to MC, divides this into two equal Parts at I; and HC is the half
Secant of the Angle of twelve Degrees, when the Radius of the Circle is
MC or CA; therefore $HC = 51117$; $NC - HC = NH = 46698$;
 $HC - aC = Ha = 11117$. The Angle iaH wants sixteen Minutes of
a Right one; we take it for a Right one, because no sensible Error arises
from it; then the Triangles HMN, Hia , are similar, and NH (46698)
is to NM (20791), as Ha (11117) is to ai (497): But ab as we have
seen is only equal to 465. But when the Distance of the Sun from the
Earth is least of all, ab increases, and is equal to 480; so that very few
of the Rays fall without the true Image of the Sun; for if AM should
want eight minutes of twelve Degrees, ai would be equal to 480. This
is the Reason why we have determin'd the whole Arch MN, that is the
Diameter of the Speculum, 25 Deg. *, lest the Rays, which can increase * 3303.
the Effect, should be wanting.

SCHOLIUM II.

Of caustic Lines by Reflexion.

THE curve Lines, mention'd in N. 3314, and the following, are 3340.
call'd caustic Lines; we have explain'd how their Points may be
discover'd *, and seen, that the Determination is not different from that * 3315.

* 3277. deliver'd for convex Speculums *, a Demonstration of which we have given in the Scholium of the last Chapter †.

† 3288. As there, so here also we have the following Proportion ; which is demonstrated in the same manner as there.

$$RD + 3RA, AB :: RA, FA.$$

but $RD + 3RA = 4RD + 3DA = 4RD + 4DE = 4RE$; for we suppose $AE = \frac{1}{4}AD$.

Therefore $4RE, 4AE :: RE, AE :: RA, FA$. Which was to be demonstrated.

3341. The Demonstration differs little from this when the Point R falls within the Circle.

Then $Aa - Dd = Bb - Aa$;

* 3289. Also instead of the Proportion $Dd + a, Aa :: RD + RA, RA$ *, we easily have this $Aa - Dd, Aa :: RA - RD, RA$.

* 3290. We also have $Bb - Aa, Aa :: FB - FA, FA$ *;

Therefore $RA - RD, RA :: FB - FA, FA$.

By Compos. and again by Comp. and Altern. $3RA - RD, AB = AD :: RA, FA$;

But $3RA - RD = 3RA + 3RD - 4RD = 3AD - 4RD = 4DE - 4RD = 4RE$.

* 3340. Therefore $4RE, 4AE :: RE, AE :: RA, AF$, as above *.

3342. From this Determination of the Point F we deduce, that the Point F is in the middle of the Chord AB, when the radiant Point is in the middle of the Chord AD; for then $RE = AE$; and therefore $RA = AF$.

3343. As the Radiant approaches the Focus recedes, and *vice versa*.

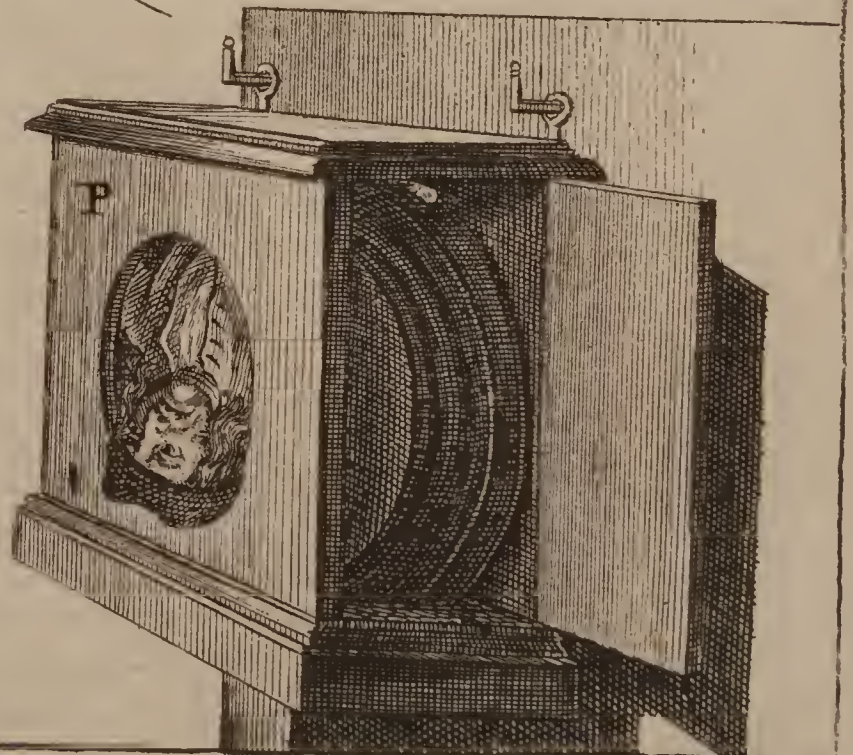
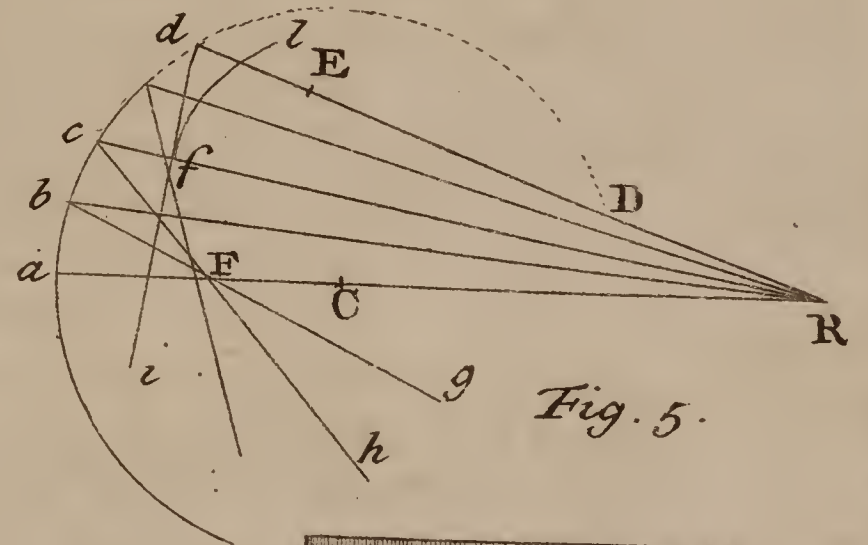
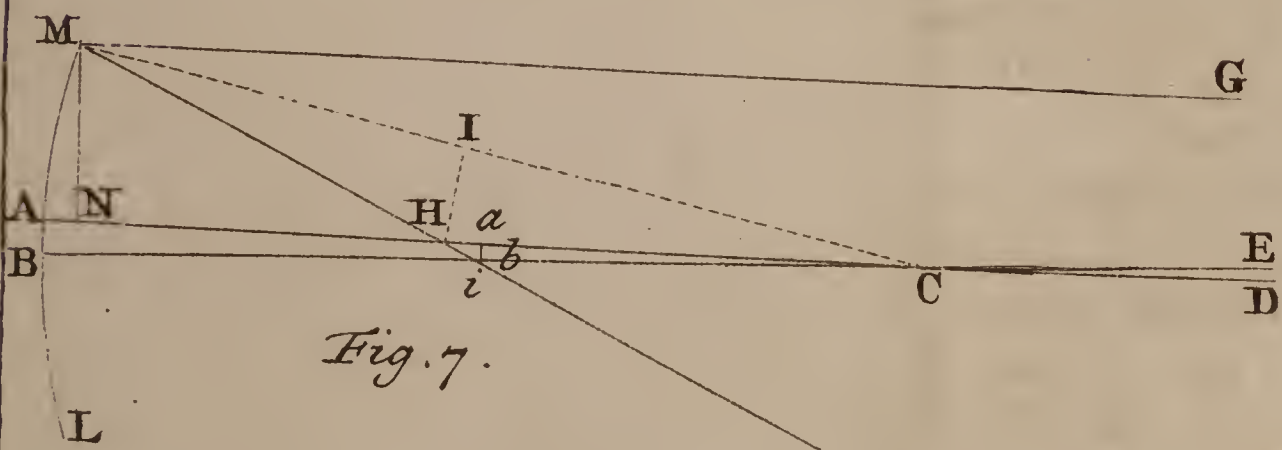
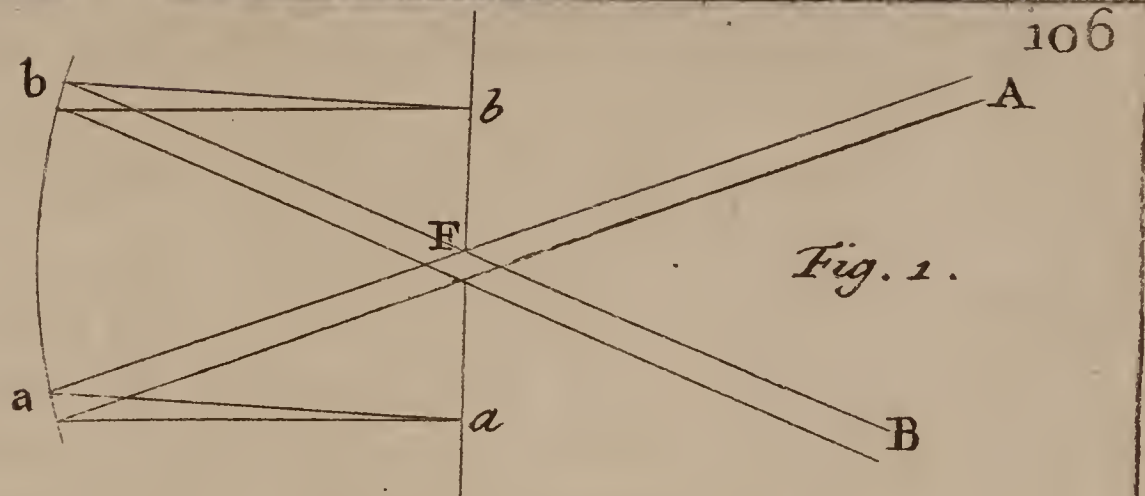
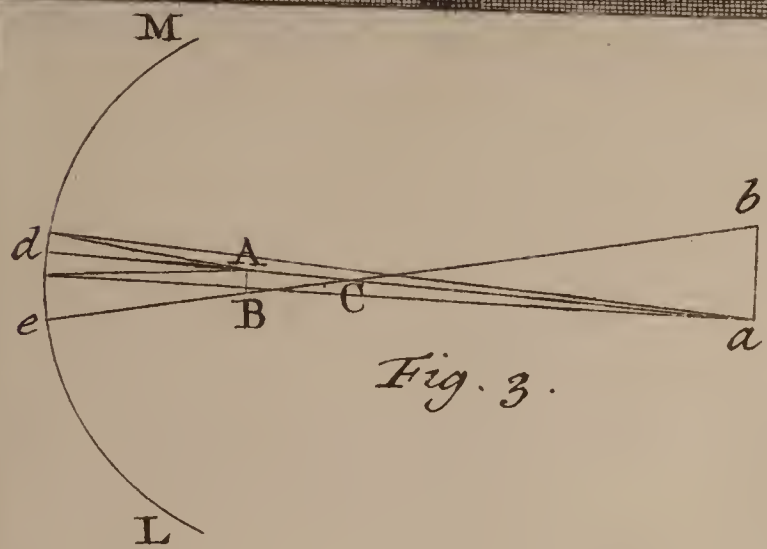
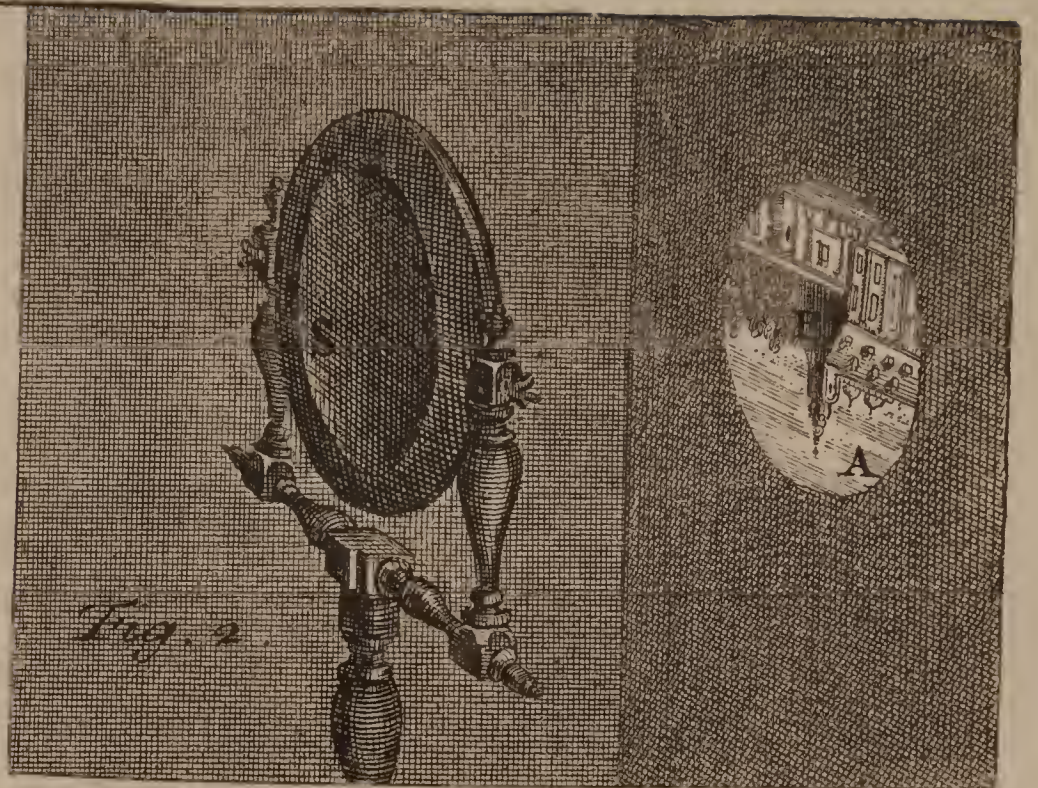
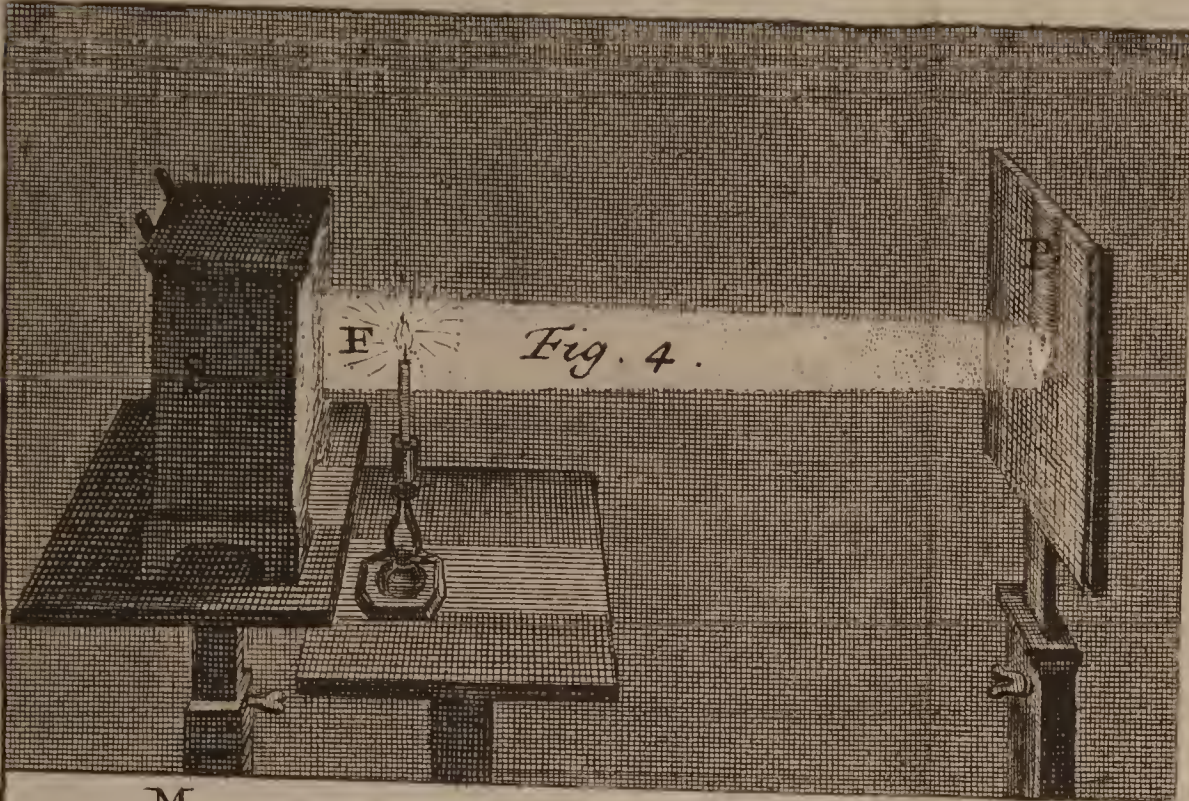
3344. When the Radiant is at E, AE infinitely exceeds RE, which is equal to nothing; therefore AF infinitely exceeds RA, that is, the reflected Rays are parallel, as has been shewn *.

* 3320. If the incident Rays are parallel, of which we have spoken in N. 3307, we take the infinite ones, RA, RE as equal, therefore AF, AE are also equal; which also follows from the general Law of Refraction *,

* 3244. If the Radiant R be between E and A, the first Term of the Proportion RE is negative; therefore also the last AF, that is, the diverging Rays are reflected, as has been said in N. 3321.

3347. In these four Figures we exhibit Curves, by considering the Reflexion of the whole Circumference of the Circle. When the radiant Point R is within the Sphere, there are four Points of the Inflection F, f, in the direct Ray, and two others d, d, in reflected Rays, supposing the incident Rays to be perpendicular to the direct Ray.

Plate 107. F.2,3,4,5. 3348. But if the Radiant Point be without the Sphere, the Reflexion can only be in Part, without the Sphere at G a G, and in Part within at G A G, the first Part G a G being remov'd; in which Case there are only two Points of Inflection.



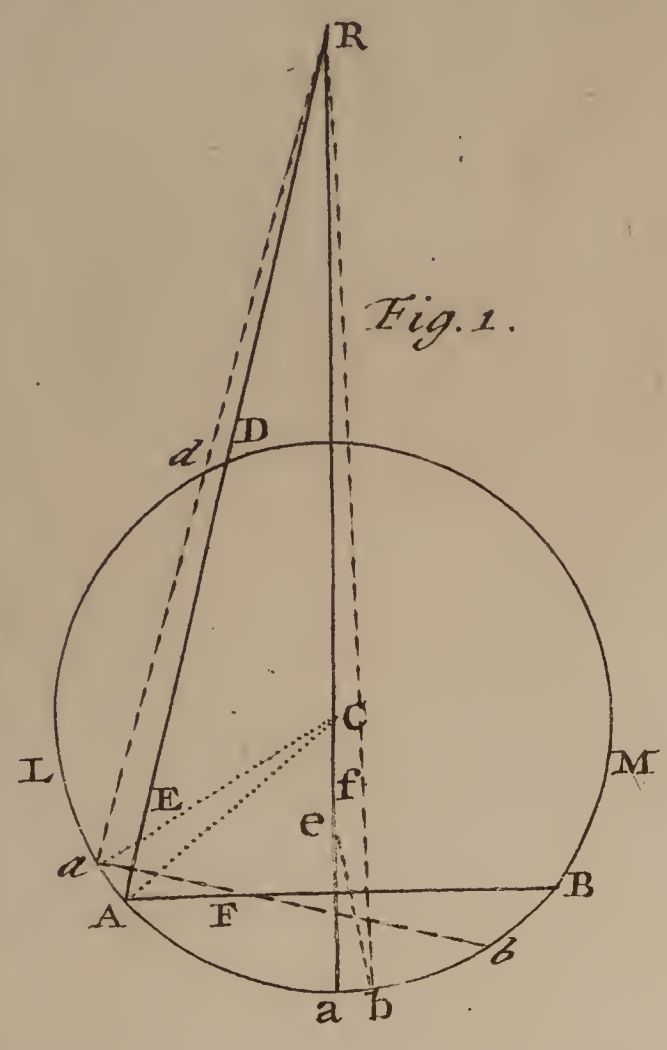


Fig. 1.

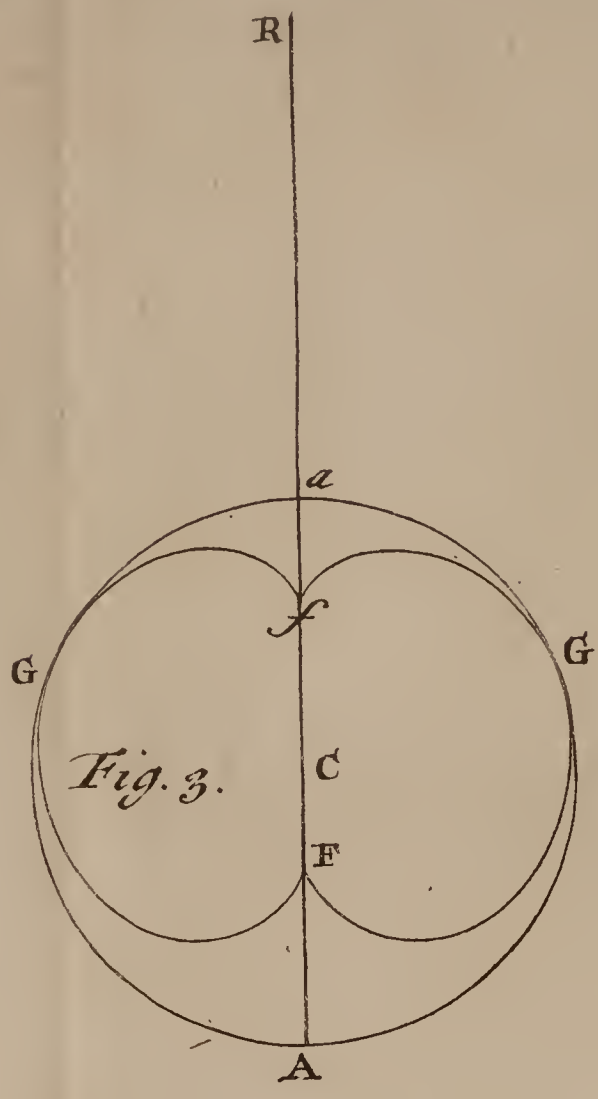


Fig. 3.

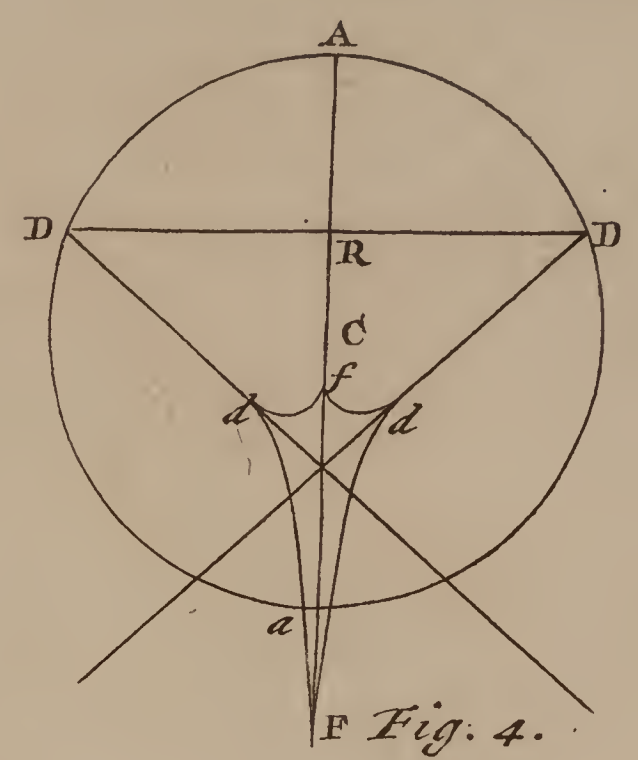


Fig. 4.

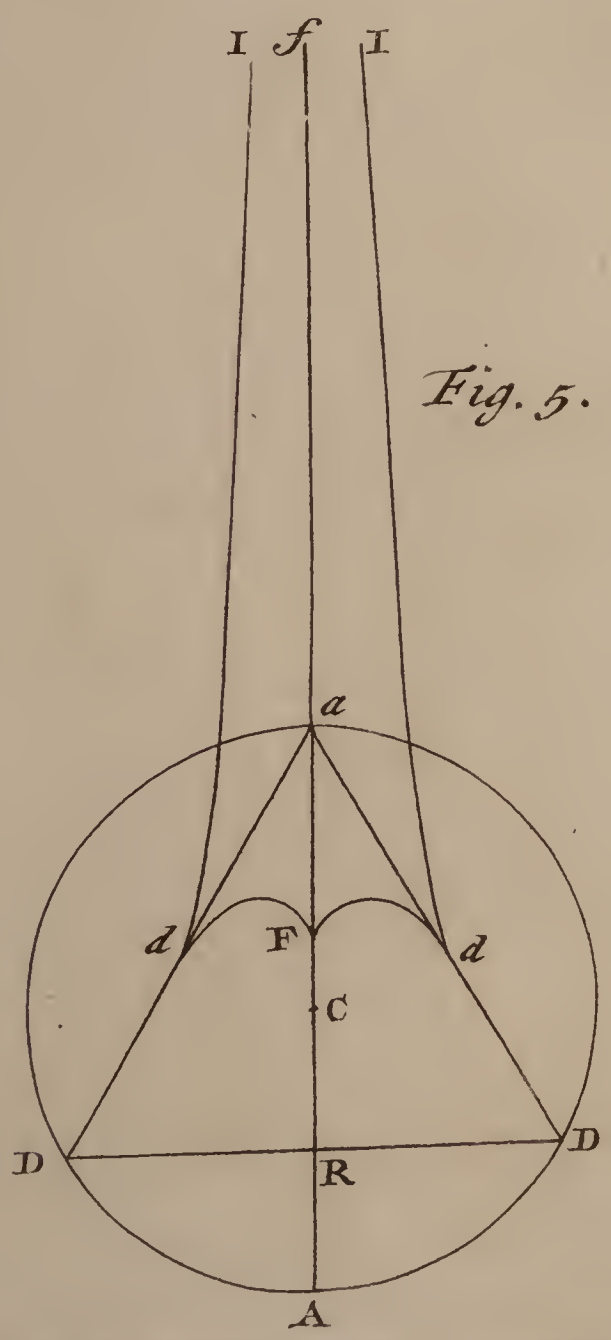


Fig. 5.

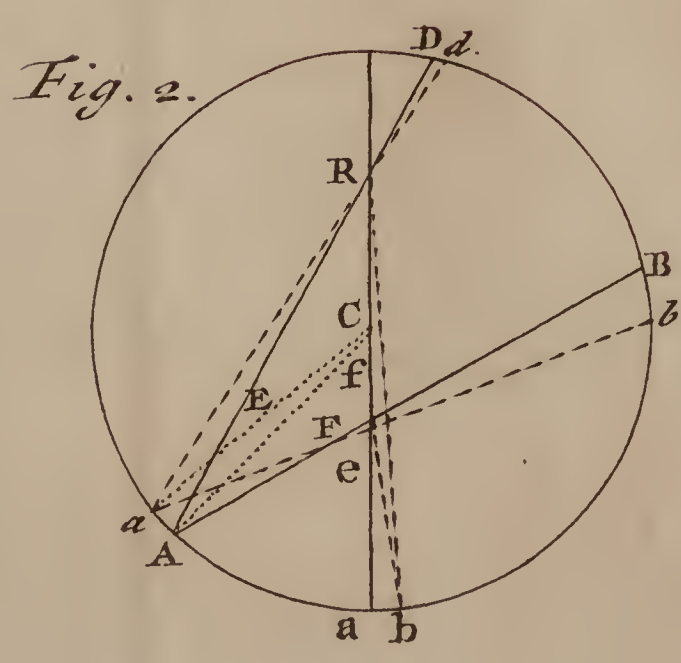


Fig. 2.

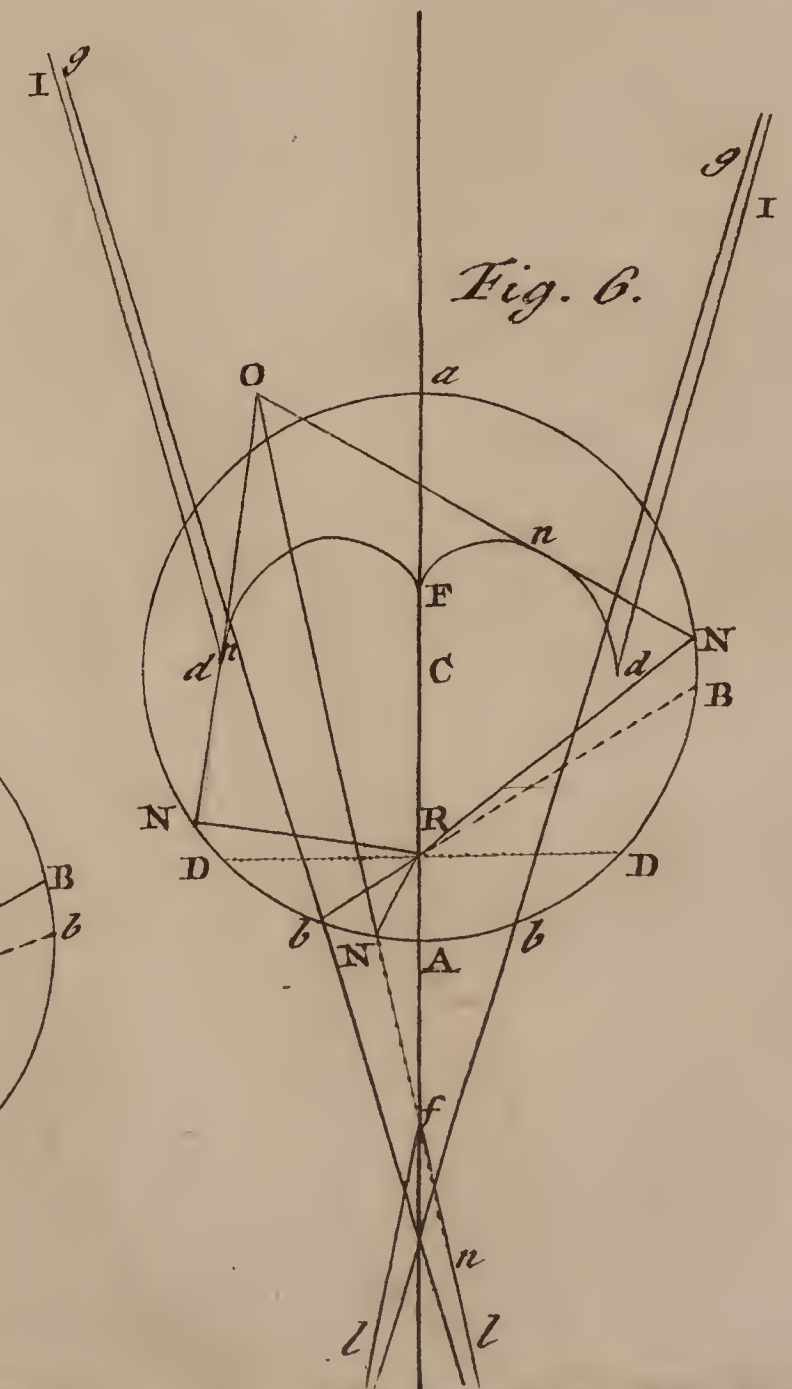


Fig. 6.



C H A P. XVII.

Of catoptric Telescopes.

WE have seen that Telescopes, made of Glasses, are imperfect for two Reasons * ; and we have only consider'd that * 3349.
Defect, which follows from the Nature of Refraction. 3221.

When we use Speculums instead of Glasses, the Imperfection from the Figure only takes Place (for we don't speak here of the Matter, or Industry of the Workman); and as this Defect is very small, the Telescopes, of which I now speak, are more perfect than others.

Let there be a concave Speculum A A ; C the Center of the Sphere, Q the Center of the Speculum itself, C Q a Ray proceeding from a Point of a distant Object, being reflected returns into itself, and with this, the Rays, proceeding from the same Point, which are looked upon as parallel, being reflected, meet at F, the middle Point between C and Q *. 3350.
Plate 108.
Fig. 1. 3297.

In the same manner, if C q be a Ray proceeding from any other Point at a Distance, and passing through the Center C, this being reflected, meets together with the neighbouring parallel and reflected Rays at E, the middle Point of the Line C q ; and thus of any other distant Points whatsoever, from which Rays can come to the Mirror. Thus the Image of a distant Object is made, and it is made by direct Rays, wherefore this is perfect, if the Mirror, or rather the Aperture of the Mirror, be not too large *. This * 3298.
Image differs from that, which has been spoken of above †, which † 3309.
is made by oblique Rays; and yet it is accurate enough, because the Rays which are but a little dispers'd are collected; but in the Telescope such an Image would be of no Use.

A small plane Mirror B B is plac'd upon the Axis C Q in such manner as to make an half Right Angle with it. This Mirror, though small, intercepts many Rays; but by that the Image is only weaken'd a little, for only the smaller Part of the Rays, which proceed from any Point of the Object, and tend to all the Points of the greater Speculum, is intercepted, the other being reflected meet and make an Image of the Point; or rather would make it, if they were not all intercepted, being reflected from the smaller Mirror. 3351.

3352. Whilst they are thus intercepted, they are reflected from the smaller Mirror in such manner, as to be before the Mirror, as they would be behind the Mirror, if they were to continue their Motion through it; which follows from the Demonstration deliver'd in N. 3264; therefore the Image is transfer'd to fe . Now if we
- * 3195. observe this through the Eye Glass OO^* , we shall have the Object very much enlarged. The Place of the Eye is determin'd,
- † 3189. 3197. as has been seen above †.
3453. The Aperture of such a Telescope is very large, if it be compared with the Aperture of a dioptric Telescope *, therefore the
- * 3221. Picture in the Eye may be very much enlarged by making use of an
- † 3220. acute Eye Glass, sufficient Clearness being preserved †. In which Case also the Vision is distinct, because the Aperture is indeed enlarged, but yet so that the Image remains distinct.
- * 3354. *The apparent Magnitude in this Telescope is refer'd to the apparent*
- * 3207. *Magnitude to the naked Eye, as has been said of other Telescopes *; and that is to this, as the Angle ODd is to the Angle FCE , but as these Angles have the equal Bases dO and FE (for such are FE , fe , and this to Sense does not differ from dO) and as these*
- † 3158. *are small †, for they are to one another as SC , or QF to Dd ; that is, as the Distance, at which the Mirror collects parallel Rays,*
- ‡ 3215. *which is the Length of the Telescope ‡, is to the Distance, at which the Eye Glass collects parallel Rays.*
3355. What has been said of the Perfection of Telescopes made of
- * 3213. Glasses *, must be refer'd to these also; we must discover by Experience what is best for any given Speculum; that is, we ought to seek the Magnitude of the Aperture by Trial, by applying different Eye Glasses, several times †, that thus, when the Length of the Telescope is given we may determine the Aperture, and the Distance of the Focus of parallel Rays for the Eye Glass.
- † 3227.
3356. Let it be now thus discover'd, that an Aperture of five Inches answers to a Length of five Feet, and that an Eye Glass is to be made use of which collects parallel Rays at the Distance of the third of an Inch; when a Telescope of a different Length shall be to be constructed equally perfect, that is, which may represent Objects, equally distinct, and with the same Clearness, we ought to observe this Rule, which we shall demonstrate in the second following
3357. Scholium, that *the Length of Telescopes be to one another as the fourth Powers of the Distances of the Focusses of the Eye Glasses, and that the Diameters of the Apertures be as the Cube of the said Distances;*
3358. *then also the Amplifications of the Lines are as the Diameters of the Apertures.*
- But

Chap. 17. of Natural Philosophy.

221

But the Aperture must be altered according to the different Light of Objects *; and it is proper also to make use of different Eye Glasses according to different Circumstances. 3359. 3230.

Objects appear inverted in this Telescope; but they are made to be erect by adding two Eye Glasses *. 3360. 3199.

This is called the *Newtonian* Telescope, from the Inventor of it; it was proposed near seventy Years ago, but it was happily brought to Practice in *England* by Mr. *John Hadley*, and carried to Perfection about twenty Years ago. 3361.

Mr. *James Gregory* had before invented another catoptric Telescope, such as are now commonly used: and these were brought to Perfection a little after the *Newtonian* ones. 3362.

The *Newtonian* Telescope is more simple and more perfect, and much to be prefer'd to the other for celestial Observations; the *Gregorian* Telescope is most convenient for seeing terrestrial Objects. 3363.

This consists of a great concave Mirror, such as is used in the *Newtonian* Telescope; of a less concave Speculum and of one, or as they are now constructed, two Eye Glasses. This is the Disposition of the Parts. 3364.

A A is the larger Speculum; this is perforated in the middle, and Q the Center of the Mirror is also the Center of the Hole *m Q n*; Plate 108. the Axis of the Telescope, which passes through the Center of the Sphere, and the Center of the Mirror, is C I. The smaller Mirror B B, upon which the Rays fall that are reflected from the greater Mirror, is so placed, that it's Axis *s c*, which passes through *c* the Center of the Sphere, and *s* the Center of the Mirror, may coincide with the Axis of the Telescope C I. The first Eye Glass V V is plac'd behind the Hole in the larger Mirror; the second is plac'd at O O, and they have their Axes in the said Axis C I. Fig. 2. 3365.

Let C Q and C *m* be Rays proceeding from two Points of a distant Object, and mutually intersecting one another in the Center C in these Lines, although the Rays be intercepted, the Images of the Point are at E and F, as has been explained in the *Newtonian* Telescope *, and E F represents the Image of the distant Object. 3366. 3351.

This Image may be considered as an Object which, setting aside the Lense V V, would have it's Image *f e* by the Reflexion of the Mirror B B *; which second Image may be remov'd to any Distance * from E F; for this depends upon the Position of the small Mirror, which is to be so plac'd that E F may be between *c* and *p*, but this is the middle Point between *c* and *s* *, but by diminishing *p F* * *f e* is remov'd. 3367. 3311. 3310.

This

3368. Every Point of the Image EF would be made by Rays proceeding from all the Points of the Mirror AA , if none of the Incident Rays were intercepted by BB , or passed through the Hole AA ; then among the Rays, that make a Point as E , there would be one as $ncEi$, which would pass through the Center c of the Sphere of the smaller Mirror; and this being reflected, would return into itself, and tend to the Point e of the second Image; for all the Rays proceeding from E , and reflected from the smaller Mirror, pass along e , and drawing Lines from all the Points of the Image ef , through the Center c , these will pass through the correspondent Points of the Image ef .
3369. Now let us suppose the Eye Glass VV to be placed near the Hole of the greater Mirror in such manner that it may intercept all the Rays passing through it. The said Rays, that pass through c , fall upon the Glass diverging, and go out converging, tending towards I^* . But the Rays that tend towards the Point as e converge more $\dagger$, and meet at the Point e , which is at a less Distance; and thus a third Image ef is made, through all the Points of which the Rays tend to I .
3370. This last Image appears magnified through the Lense OO , and this is the Use of this Telescope. But the Rays that tend towards I , and are converging, converge more, and meet at D^* ; and this is the Place of the Eye; for unless this be placed there, all the Rays, passing through the Eye Glass OO , will not be able to penetrate into the Eye, and the Field would be less, as has been
- * 3189.3197. often seen *.
3371. The Plate is fasten'd at D , in whose Center there is a small Hole. This excludes all extraneous and troublesome Light; which, when the Hole Increases a little, enters into the Eye.
3372. When one Eye Glass only is made use of, the Image, e, f , is plac'd at a small Distance from the Hole nm^* , and a Spectator beholds this through the Eye Glass.
- * 3362.
3373. The Amplification, that is the Increase of the apparent Magnitude, is determined in this Telescope as in the others; for this Magnitude to the naked Eye, is to that seen through the Telescope as the Angle ECF to the Angle $x D d^*$, the Comparifon of which is more intricate than in the Examples which we have hitherto had.
- * 3207.3352.
3374. But the apparent Magnitude through the Telescope is to that with the naked Eye, in this Case, as we demonstrate in the third Scholium following, in a Ratio compounded of these three Ratios of

of FQ to Fc of cy to yr (y is the Focus of parallel Rays of the Glafs VV) and lastly of fI to fd ; we suppose f to be in the Focus of the Glafs OO , from which this Image is hardly removed, except there be a fault in the Eye of the Spectator. The Antecedents and Consequents being multiplied, there is produced the Ratio which we seek.

We discover by Trial what is required to make the Telescope as perfect as possible, as has been seen of other Telescopes *; and we afterwards determine by Computation, how another equally perfect, that is, which represents Objects equally clear, and equally distinct, may be constructed; but the Trials made with the *Newtonian* Telescope * are of use here also.

3375.

* 3227. 3355.

* 3356.

3376.

But as the Telescope, spoken of here, consists of many Parts, this may be alter'd many Ways, keeping the abovementioned Perfection.

We now suppose, a Telescope being given, whether a *Newtonian*, or *Gregorian* one, with one or two Eye Glasses, that another equally perfect is to be made, whether *Newtonian*, a Speculum being given, or *Gregorian*, two Speculums being given, and the Lense VV , if two are to be made use of; these Parts being join'd at Pleasure, yet in such manner that the Image ef , if VV be wanting, or ef if VV be present, be plac'd in such manner, that the Lense OO may be conveniently fitted to the Telescope. The Aperture of the greater Speculum is sought, and the Convexity of the Glafs OO .

3377.

We don't want a new Rule to determine the Aperture from that, which we gave for the *Newtonian* Telescope *, it follows, that *the Diameters of the Apertures in different Telescopes, are to one another as are the Cubes of the biquadratic Roots of the Lengths*. The same Rule obtains in these, if we take the Distance FQ for the Length, as in the *Newtonian* Telescope. But before we determine the Convexity of the last Eye Glafs, we must determine the Ratio, which is between the Image which we should observe through this last Lense OO , and the first Image EF . If the Lense VV be wanting, this Ratio is (as will be seen in the third Scholium) that which is given between ps and Fp .

* 3357.

3378.

3379.

If two Glasses are to be made use of, and VV be given, we have f ; for pF , pc , pf , are proportional, as follows from the Proportion abovemention'd *, we discover I , because cy , cr , cI , are also in continued Proportion †. We also discover f , for fy , fr , ff , are also Proportionals ‡. These being given, the Ratio sought, which

3380.

* 3310.

† 3035.

‡ 3035.

is between ef and EF , is as we shall see in the third Scholium, made up of the Ratios now known, of If to yr and cr to cF , the Antecedents and Consequents of which should be multiplied.

3381. But the Ratio between the Diameters of the last Image and the first being given, by dividing the Antecedent by the Consequent, we have the Exponent of the Ratio of the first Amplification, for so we shall call it, to distinguish it from the Amplification, which the Telescope itself produces.

This Exponent being multiplied by the Square Root of the Length of the Telescope, the Product is in the Ratio of the Distance df , that is of that, at which the Glass OO collects parallel Rays, which also we express in this manner. That in different Telescopes, the last Eye Glasses must be so constructed, that the Products of the Exponents of the first Amplifications by the biquadratic Roots of the Lengths, may be to one another as the Distances of the Focusses of the said Lenses; which Rule is demonstrated in the fourth Scholium.

3383. With regard to these Computations the *Newtonian* Telescope differs from the *Gregorian* in this only; in the first a Spectator sees the Image equal to EF through the Eye Glass, in the second he observes the Image ef .

3384. If the Images ef and EF in the *Gregorian* Telescope be equal, setting aside the Diminution of Light from the Reflexion and Refraction, these Images will also be equally lucid; so that it matters

3385. not which we behold; and the *Newtonian Telescope* is compared with the *Gregorian*, if instead of the *Newtonian* we conceive a *Gregorian Telescope* in which the said Images are equal, that is, in which the Exponent of the first Amplification is Unity.

3386. Therefore it is not necessary, as has been shewn above*, when

* 3375. the Aperture and Convexity of the Eye Glass for the *Newtonian*

† 3356. Telescope are determin'd by Experiments †, to make new Trials, in order to construct a *Gregorian Telescope* equally perfect: The Computation may be made with those Things given which were mention'd in N. 3377.

3387. When two Telescopes, the one *Newtonian*, the other *Gregorian*, are of equal Lengths, that is, when the greater Speculums are equally concave, unless the Apertures of the Speculums be equal, they

* 3333. 3384. will not be equally perfect*; and if they be equally perfect, Objects will appear equally magnified, howsoever the Figure and Position of the smaller Speculum, and inner Glass be varied in the *Gregorian* one, for the Rule, mention'd above, in a peculiar Case*, is

3388. universal, which takes Place in the Comparison of any Telescopes what-

* 3358. ever,

ever whether of the same or of a different Kind, that the Amplifications of Objects are as the Apertures when the Clearness is the same.

For the Clearness depends upon the Light, with which the Picture of an Object in the Eye is illuminated; if the Light be alter'd, the Clearness will remain the same in this Case only, if the Picture be alter'd in the same manner; for Example, if it be doubled, when the Light is doubled, &c. that is, the Picture and Light ought to be in the same Ratio; but the Light is as the Aperture *, * 3220. therefore the Picture is in the same Ratio also.

In the last Scholium of this Chapter, I shall demonstrate the Rules concerning the Comparison of the *Gregorian* Telescopes; and I shall also speak of comparing dioptric Telescopes with catoptric ones; concerning which Comparison I shall only give one Rule here, which will have for it's Foundation this, viz. that the Telescopes mention'd in N. 3228, and 3356, are equally perfect.

The Length of any dioptric Telescope equally perfect with that mention'd in N. 3228, being given, we want to know the Length of a catoptric Telescope, which, if it be as perfect as the other, represents Objects amplified equally with the Telescope proposed. The Rule is this.

The Square of the given Length is divided by $55\frac{5}{9}$, and the Cube Root of the Quotient expresses the Length sought. 3391.

If the Length of the catoptric Telescope were given, and that of the dioptric one sought, the Cube of the given Length should be multiplied by $55\frac{5}{9}$, and the Square Root of the Product would give the Length. 3392.

But this Number $55\frac{5}{9}$ was determin'd for Lengths, expressed in *Rhinland* Feet, therefore a Length of six Inches should be expressed no otherwise than by $\frac{1}{2}$, or O, 5. 3393.

SCHOLIUM I.

Of the spreading of Rays from the Reflexion of a concave Speculum.

LET there be a concave Speculum ML; C the Center of the Sphere; 3394.
DCA a direct Ray; *a* the Focus of Rays parallel to it, dividing Pl. 108.
CA into two equal Parts *; let there be other parallel Rays also at a Fig. 3.
greater Distance, and the last of these BM, which is reflected along MH*i*. * 3297.
When the Rays are at a small Distance, from A, being reflected they meet at *a*; but this last cuts CA in H; and if the parallel Rays take up a Space on the Surface of the Mirror, whose Semi-Diameter is AM, that is, if this be the Semi-Diameter of the Aperture; all these being re-

lected pass through the small Space whose Semi-Diameter is ai ; many Rays indeed mutually intersect one another every where between H and a ; but they are collected no where in so great Plenty as at a : And therefore the Dispersion is to be referr'd to this Point at a , and there measur'd.

3395. This small Line ai , if Ha remains, is as the Angle aHi or MHA ; if the Angle be not alter'd, the same small Line ai , is as Ha ; therefore, as these two are continually chang'd, when M recedes or approaches, ai is in a Ratio compounded of the two.

3396. MHC is an Isosceles Triangle *; therefore the Angle MHA is

* 3297. double the Angle MCA †; and therefore MHA is in the Ratio of

† 32. El. 1. the Arch AM .

3397. With the Center C , through the Point a describe a Circle, which cuts the Line CM in I ; in which Point if there be a Perpendicular to CM ,

* 16. El. 3. it will touch the Circle at I *; and pass through H , by reason that HC , HM are equal. Let D be the End of the Diameter of the same Circle, and the Square of the Line HI will be equal to the Rectangle made of

* 36. El. 3. HD multiplied into Ha *. But as we only speak of the Cases in which Ha is small, HD is taken as constant; and the said Rectangle is in

* 1. El. 6. the Proportion of Ha *; in the Ratio of which therefore is the Square of the Line HI . But HI to Sense agrees with the Arch aI , which is in the Ratio of AM ; therefore Ha is in the duplicate Ratio of the Arch AM ; if with these be join'd the Ratio of the same Arch, which is the Ratio of the Angle AHM *, we have the triplicate Ratio of AM , in which Ratio is ai †.

† 3395.

3398. Therefore the Diameter of the Dispersion, is as the Cube of the Diameter of the Aperture, in the same Mirror.

3399. Let us now suppose, the Mirrors to be different, but the Apertures equal. Let mn be a Mirror; c the Center of the Sphere; ca a direct Ray; f the Focus of parallel Rays; am the Semi-Diameter of the Aperture, equal to AM . The last Ray bm is reflected along mrp , and the Semi-Diameter of the Aberration is pf , which we must compare with ai .

Let us suppose an to be to am , as af is to Aa ; and let the incident Ray at n be reflected along nbo ; so that fo may be the Semi-Diameter of the Dispersion, when an is the Semi-Diameter of the Aperture.

From the Construction it follows that the Figures $AH ai HM$ and $abfo bn$ are similar;

And therefore $ai, fo :: Aa, af$.

* 3398. We also have $fo, fp :: an^3, am^3$ * :: af^3, Aa^3 .

But ai is to fp in a Ratio compounded of the Ratios of ai to fo and fo to fp ; that is of the Ratio's of Aa to af and af^3 to Aa^3 ,

or $\frac{I}{Aa^2}$ to $\frac{I}{af^2}$.

3400. Therefore, when the Aperture is determin'd, the Semi-Diameter of the Dispersion, which is as the whole Diameter, is in the inverse duplicate Ratio of the Distance of the Focus of parallel Rays, or the Length of the Telescope, if this be consider'd.

We

Chap. 17. of Natural Philosophy.

227

We have now a general Rule concerning the Dispersion; that *the Diameter of the Spot, which the dispersed Rays make, is in the direct triplicate Ratio of the Aperture of the Mirror* *, and *the inverse duplicate Ratio of the Distance of the Focus of parallel Rays* †.

3401.

3398.

† 3400.

SCHOLIUM II.

Of comparing together the Newtonian Telescopes.

CAtoptric Telescopes are compar'd together, as has been said of dioptric ones; those are equally perfect, which represent Objects equally distinct, and equally clear *. The Clearness in these, as in the others, is directly as the Aperture, and inversly as the Picture of the Object in the Eye †. But the Diameter of this Picture is in the direct Ratio of the Diameter of the Image in the Telescope, which is as it's Length, and the inverse Ratio of the Distance of the Focus of the Eye Glafs; for all these Things agree to this Telescope in the same Manner as to those, which are made of Glaffes *.

3402.

* 3225.

† 3231.

* 3231.

Let a be the Diameter of the Aperture; l the Length of the Telescope; f the Distance of the Focus of the Eye Glafs; the Clearness of the Telescope will be as the Square of this Fraction $\frac{af}{l}$ *.

3403.

* 3231.

This Fraction is not alter'd, by altering the Length of the Telescope at Pleasure, if the Rule of N. 3357 be observ'd. According to which a is as f^3 , af as f^4 ; l also is as f^4 ; therefore the Numerator and Denominator of the Fraction are alter'd in the same Ratio; and this, which is in the subduplicate ratio of the Clearness, is not alter'd.

3404.

The Distinction is the same, when the Spot in the Bottom of the Eye, which represents a Point, has the same Magnitude *; but this Spot in the Eye is the Picture of another Spot, which the Rays, that proceed from a Point of the Object, make in the Image of it.

3405.

* 3232.

The Diameter of this last Spot is as $\frac{a^3}{l^2}$ *. But the Picture of this

* 3401.

Diameter, is as AD directly, and inversly as the Distance of the Focus of the Eye Glafs †. Therefore the Diameter of the Spot in the

† 3231.

Eye is as $\frac{a^3}{l^2 f}$. Now if, according to the Rule ||, a be as f^3 , and l

|| 3351.

as f^4 , the Numerator and Denominator of the Fraction are both in the Ratio of f^9 ; that is, they are increased, and diminish'd in the same Ratio, and the Fraction is not alter'd, and the whole Picture in the Eye is equally distinct.

S C H O L I U M III.

Of determining the Amplifications in the Gregorian Telescopes.

3406.
Plate 108.
Fig. 2.

* 3373.

* 3035.

* 3035.

WE said that the apparent Magnitude to the naked Eye is to that through the *Gregorian Telescope*, as the Angle ECF , is to the $\propto Dd$ *; but this Ratio is compounded of the Ratios of the Angle ECF to EcF or tcr ; or tcr to tIr ; and lastly of tIr , which is $\propto Id$, to $\propto Dd$. The first Ratio is that which is between Fc and FC , or FQ ; the second is between Ir and cr , but cy , cr , cI , are proportional *; and by Invers. and Divis. $cr - cy = yr$, $cy :: cI - cr = Ir$, cr ; therefore the second of the said three Ratios is that, which is between yr and cy ; the third is that between Dd and Id ; but If , Id , ID are Proportionals *; by Convers. and Invers. $If - Id = fd$, $fI :: Id - ID = Dd$, Id , and the third Ratio is that between fd and fI ; but these Ratios are the same, as those mention'd in N. 3374.

What has been said in N. 3379 and 3380 about determining the first Amplification, that is, about comparing the different Images of Objects, shall be now examin'd also.

3407.

Let us suppose one Eye Glass only, to be made use of, and we must demonstrate that, which is deliver'd in N. 3379, namely, that ps is to Fp as ef is to EF , that is, as fc is to cF .

3408.

* 3310.

We have fs , $sF :: ps = pc$, Fp *.

By Division $fs - sF = fF$, $sF :: pc - Fp = cF$, Fp .

By Altern. and Divis. $fF - cF = fc$, $cF :: sF - Fp = ps$, Fp . Q.D.E.

3409.

What has been said in N. 3380, concerning the first Amplification with two Eye Glasses, scarce needs to be demonstrated; namely that ef is to EF in a Ratio compounded of If to Ir and cr to cF ; for ef is to EF in a Ratio compounded of ef to rt and rt to EF ; but the first is that which is between If and Ir , by reason of the similar Triangles rtI , feI . But the second Ratio of rt to EF , by reason of the similar Triangles ctr , cFE , is that, which is between cr and cF .

S C H O L I U M IV.

Of comparing the Gregorian Telescopes with one another, and with the Newtonian Telescopes; as also of comparing catoptric and dioptric Telescopes.

3410.

WHAT was delivered in the second Scholium, is of Use here also; therefore we again suppose a to express the Diameter of the Aperture of the Telescope; l the Length; and f the Distance of the Focus of the last Eye Glass, that is, of that next the Eye.

Let

Fig. 1.

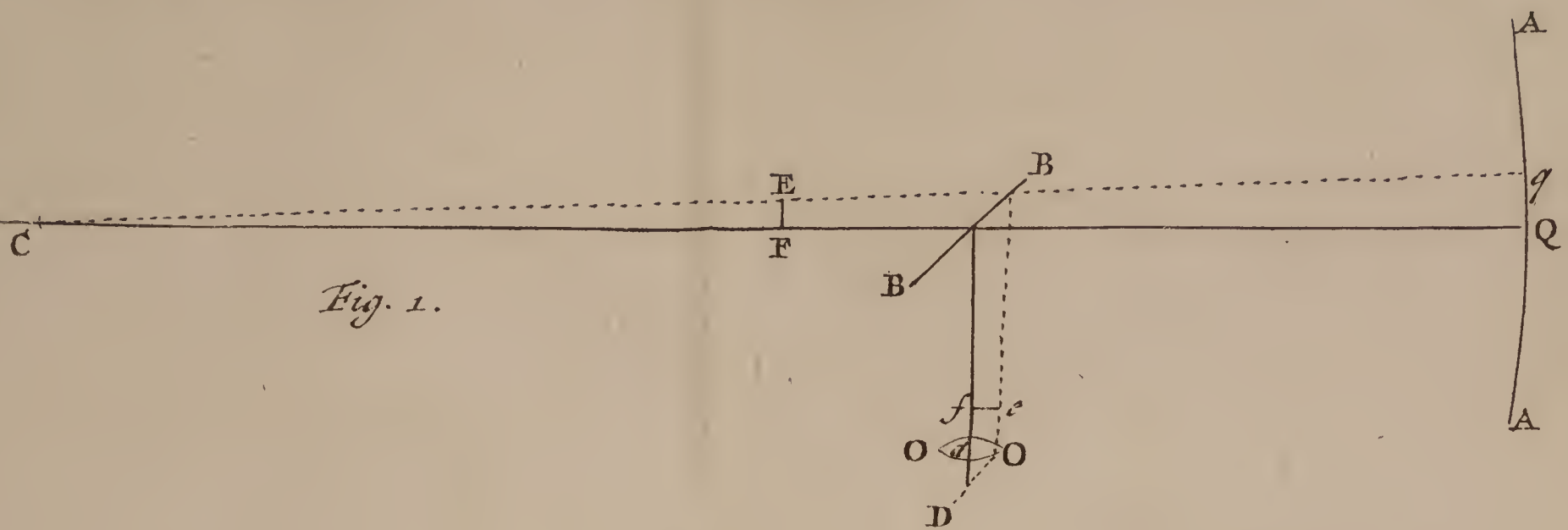


Fig. 2.

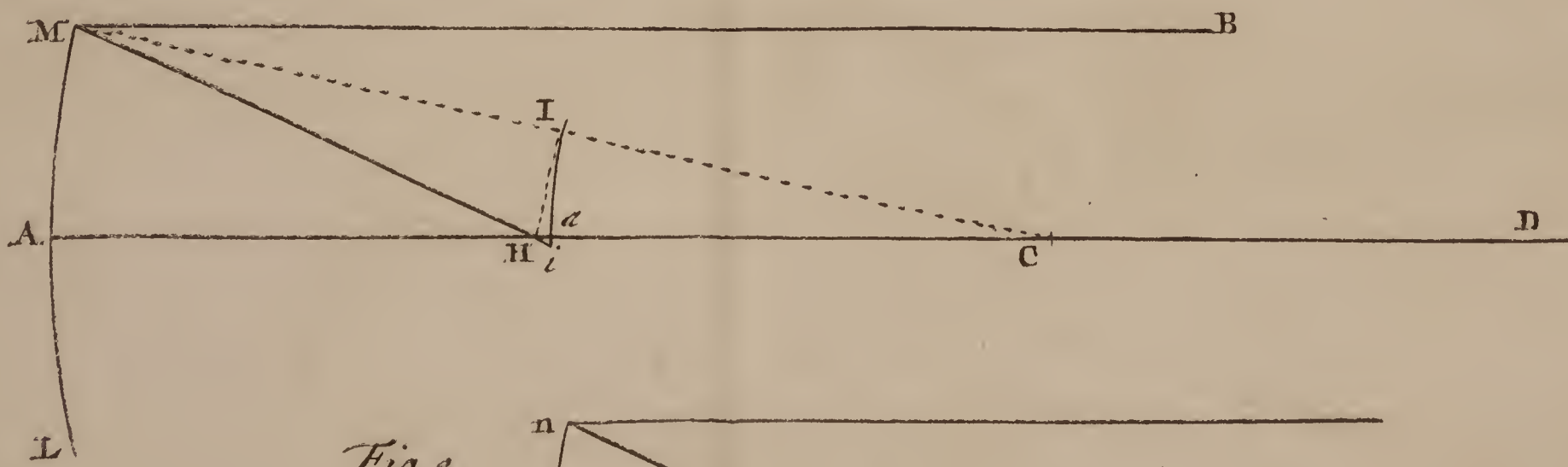
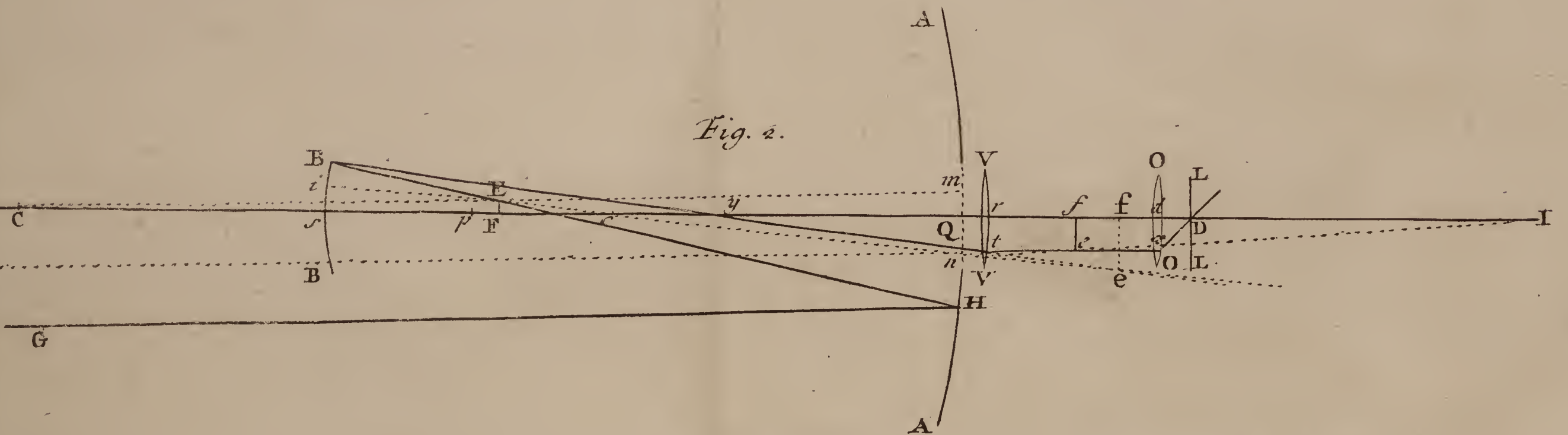
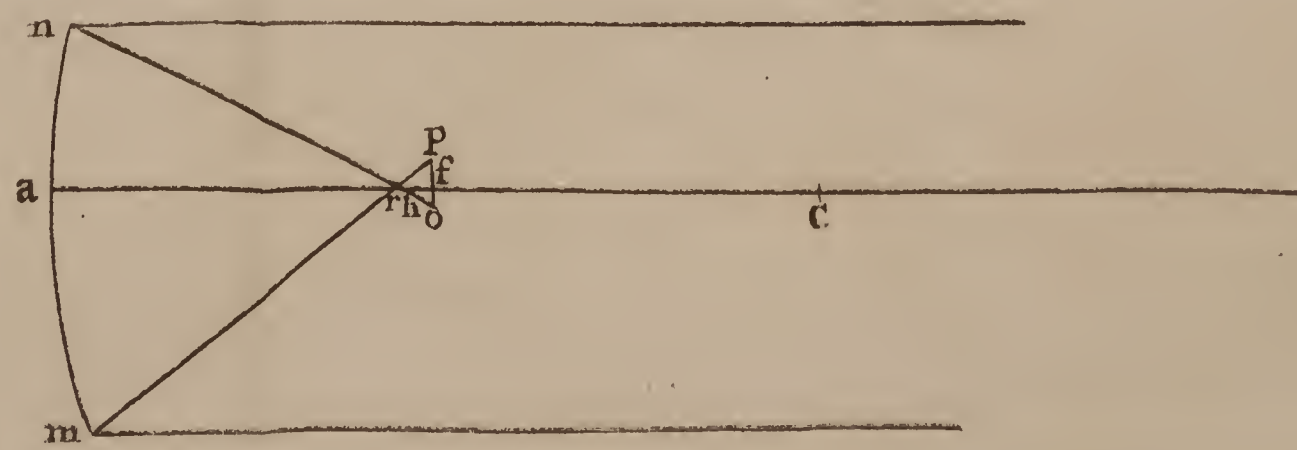


Fig. 3.



Let us moreover suppose, any Line in the last Image, which a Spectator beholds immediately, through the Glass next to the Eye, to be to the same Line in the first, which is made by the greater Speculum, as n to 1; so that n may be the Exponent of the first Amplification*. The Telescope being now given, another, of any Length, is proposed to be constructed in such manner, that Objects may appear equally distinct and clear. 3381.

As the Length of the Telescope is given, the greater Speculum is given, whose Aperture is to be determin'd; the Convexity of the last Eye Glass must be determin'd, and these two things are sufficient; for there are only two Conditions of the Problem, that the Clearness and Distinctness may be preserv'd; wherefore the smaller Speculum may be varied at Pleasure, and the first Eye Glass, when two are used; these two may also be plac'd at Pleasure, but Care must be taken that the Case be not impossible or inconvenient*. 3411.

The Clearness of the Telescope is directly as the Aperture, and inversely as the Picture in the Eye; the Diameter of the Picture is directly as the Image, and inversely as f *, the Diameter of the first Image is as l †, but we speak of the second, whose Diameter is as nl ‖; therefore the Diameter of the Picture is as $\frac{nl}{f}$, and the Clearness in the duplicate Ratio of

this Fraction $\frac{af}{nl}$ ‡. 3403.

The Distinctness of every one of the Points is had by considering the Spot, which represents a Point of the Object in the Image, the Diameter of which Spot is as $\frac{a^3}{l^2}$ *, this in the last Image is as $\frac{na^3}{l^2}$, and the Picture of it in the Eye as $\frac{na^3}{fl^2}$ †. 3413. 3401.

If therefore the Clearness and Distinctness of Telescopes be the same, these Fractions $\frac{af}{nl}$ and $\frac{na^3}{fl^2}$ are also constant for all Telescopes equally perfect. Therefore we may put each Fraction equal to a constant Quantity, which we denote by Unity; but these are not therefore equal to one another; because we do not speak of the same Unity for both Fractions.

We have now two Equations, which we change into these $af = nl$ and $na^3 = fl^2$; either gives the Value of f ; which being compar'd we have $\frac{nl}{a} = \frac{na^3}{l^2}$, that is, $l^{\frac{3}{4}} = a$, as has been said in N. 3378, where we observ'd, that this Rule agreed with that which was given for the Newtonian Telescope; wherefore in all catoptric Telescopes, the Aperture is determin'd in the same Manner, which depends upon the Length alone. 3414. 3415.

Whence

3416. Whence we deduce, that *the Amplification of an Object seen through a Telescope, depends also upon the Length alone*; for this remaining the same the Aperture remains, which is in the Ratio of the Amplification *.
- * 3388. Therefore in all Telescopes, of the same Length, equally perfect, Objects appear of the same Magnitude, whether they be *Newtonian*, or *Gregorian* Telescopes, or if instead of a small concave Speculum, they have a convex one; such as *Cassegrain* proposed; who, although he proposed his Telescope, which differ'd little from the *Gregorian* Telescope, a long Time after the Description of the *Gregorian* Telescope was made publick, call'd himself the Inventor, because, as it seems, he had not seen *Gregory's* Book.
- 3417.
3418. Now to discover f , we must have Recourse to the Equation $af = nl$ *;
- * 3414. instead of a I substitute the Value $l^{\frac{3}{4}}$ and there is given $fl^{\frac{3}{4}} = nl$, or $f = n l^{\frac{1}{4}}$, as has been shewn above †.
- † 3382.
3419. We have seen that n in the *Gregorian Telescope* may be changed at Pleasure *; then all Things remaining the same f only must be changed in the same Ratio; for l remaining, f is changed as n , in the last Equation in the *Newtonian* Telescope $n = 1$ †; and, if this be compar'd with the equal *Gregorian* Telescope, the Distances of the Foci of the Eye Glasses will be to one another, as 1 to n ; and thus any catoptric Telescopes are compar'd together.
3420. But if dioptric Telescopes are to be compar'd with catoptric ones, two Determinations by Experiments are requir'd. For the Dispersion of the Rays, upon which the Distinctness of the Objects depends, is not subject to the same Laws in these different Telescopes: *In catoptric Telescopes, the Light in the Spot, which is the Representation of the Point, is suddenly weaken'd, as you recede from the Center, but not in others in the same manner.* Therefore we suppose the Telescopes mention'd in N. 3328, 3356, to be equally perfect. And the Comparison will be founded upon the
- * 3388. Rule deliver'd above *, by which it appears, that Telescopes of any kind, if they be equally perfect, amplify Objects equally, when the Apertures are equal; the Demonstration of which is universal †.
- † 3389.
3422. Let A be the Aperture, and L the Length of the dioptric Telescope given; a the Aperture, l the Length of the catoptric Telescope given; x and z the Lengths of two other Telescopes, of which the first is a dioptric, the other a catoptric Telescope, which are equally perfect with those given, and agree among themselves as far as relates to the Amplification, that is, have equal Apertures.

Then $L, x :: A^2, \frac{A^2 x}{L} =$ the Square of the Diameter of the Aperture of the Telescope x *.

* 3229.3231.

And $l^3, z^3 :: a^4, \frac{a^4 z^3}{l^3} =$ the Biquadrate of the Diameter of the Aperture of the Telescope z †.

† 3378.3414.

These Apertures are equal, therefore $\frac{A^4 x^2}{L^2} = \frac{a^4 z^3}{l}$.

The Quantities $\frac{A^4}{L^2}$ and $\frac{a^4}{l^3}$ are constant *, whatsoever the Telescopes given be. Let us suppose these to be as 1 to m , and we shall have $x^2 = mz^3$; now according to N. 3228 and 3256, let $A = 3$; $L = 30$; $a = 5$; it will be $m = 55\frac{5}{9}$, whence appears what was mention'd above.

We ought to take Notice here, that the Rule of N. 3383 does not very accurately agree with the Telescopes of N. 3328 and 3356, unless we increase the Distance of the Focus of the Eye Glass in the *Hugenian* Telescope $\frac{1}{36}$ of an Inch. *Hugens* determin'd the Distance of the Focus three Inches and three tenths (for there is an Error in N. 3228.) we ought to put three Inches and a third; then in these Telescopes the linear Amplifications are 108 and 180, accurately to one another as 3 to 5, that is, as the Diameters of the Apertures. 3423.

We have already observ'd that many Things must be alter'd in Telescopes according to Circumstances *; among other Things we said, that Glasses are not equally perfect; which must also be referr'd to Speculums; which, as well as Glasses, are not always made of equally fit Matter; all these Things we set aside, as has been said before.

C H A P. XVIII.

Of the Magic Lantern.

THERE are several other Machines constructed, in which, 3424.
by Speculums and Lenses joined, useful and pleasant Spectacles are represented; the Explanation of which is easily deduc'd from what is said before.

I shall make choice of one only, among others, to be explain'd, whereby Figures, painted on a small Glass, are represented very large upon a white Plane. The Phænomenon is strange enough, to deserve a particular Explanation. The Machine is called a *Magic Lantern*, whereby it is represented; not indeed passed over by optical Writers, yet not sufficiently treated of.

There is a Wooden Box, about a Foot and an half long, whose 3425.
Breadth and Height is fourteen Inches; in this there is a concave Plate 109.
Speculum S, of eight Inches Diameter, the Diameter of whose Fig. 1.
Sphere is a Foot and an half: This Speculum is applied to a Stand, which moves between Rulers along the Box.

There is also in this a Lamp L, which is supported by a Wooden 3426.
Stand, movable between Rulers at the Side of the Box, along it.
The

The Tube of the Lamp is prominent in such manner, that the Center of the Flame answers to the Center of the Surface of the Speculum; this Flame consists of four Flames, which mutually touching one another make a square Flame, whose Side exceeds two Inches.

3427. There is an oblong Aperture in the upper Plane of the Box, which is closed with a Cover, moveable between Rulers; through this passes C, which (as appears in Fig. 3.) stands out above the Box about a Foot and an half high. This is moveable with it's Top; the aforesaid Aperture remaining shut; which is plac'd so that it may answer to the Lamp.

3428. In the smaller Side of the Box there is a round Hole, of the Diameter of five Inches; in which there is a convex Glass V of the same Diameter: This is terminated on both Sides by a convex Surface, a Portion of a Sphere, whose Diameter is equal to one Foot: If an Axis of this Glass be conceived, it will be perpendicular to the Surface of the Speculum in the Center of it, as also to the Plane of the Flame through whose middle Point it passes.

This Hole is shut and open'd by means of a Board moveable between Rulers, which is mov'd by a Cylinder, standing out of the Box at E.

3429. The Tube T answers to this Hole without the Box, whose Length and Diameter are about six Inches, in whose Extremity there is a Ring, in which a second Tube *t* moves, of the Diameter of about four Inches, and Length of five or six Inches.

3430. In this smaller Tube there are two Lenses; the first at the Extremity which is thrust into the Tube T, and which is of the same Convexity with the Glass V, and of the Diameter of three Inches and an half; the second Lense, which is three Inches distant from the first, is more plane and terminated by Portions of a Sphere of the Diameter of four Feet. Between these Glasses, at the Distance of an Inch from the second, there is a Wooden Ring, with which the Tube is closed, a circular Aperture being left, of the Diameter of an Inch and a quarter.

The Objects to be represented are painted upon plane and thin Glass, which is moved without the Box near the Glass V, between this and the Tube T, the Picture being in an inverted Position. If these Glasses be round, they have the Diameter of five Inches; that they may be conveniently mov'd, they are fasten'd in a Frame of Wood, and three may be put into the same Frame. The Figures are also painted upon long Glasses, which are also put into

wooden Frames, and the Figures are represented successively. These Frames move between the Rulers R P, R P, which are Plate 110. join'd to the square Board M, to which is fasten'd the Tube T. Fig. 1.

This whole Box is supported by a Stand, whereby it is fix'd at any Height, within certain Limits; the Planes *n, n*, are join'd to Plate 109. the Box, and are mov'd between Rulers along the Planes *m, m*, Fig. 3. which make the Stand; in each of them there is a Slit; the Box is placed at the Height required, by Means of Screws fixed in the Stand, as *c*, and which move along the Slits.

EXPERIMENT I.

The whole Machine is plac'd at the Distance of fifteen, or twenty, or thirty Feet from a white Plane, which is different according to the Magnitude of this Plane; for this Distance should exceed the Length of the Plane but a little. The Box is fasten'd at such an Height, that the Glasse, in the Side of the Box, may answer to the middle of the Plane. The Lamp being lighted the Box is shut, and the Figures, painted upon the Glass, are represented upon the white Plane. By moving the Tube, in which the two Lenses are, we discover the Position of it requir'd to make the Representation distinct.

But the Disposition of the Parts of this Machine, which are of use in exhibiting this Spectacle, must be more particularly explain'd.

The Parts are these, S S the Mirror; *ll* the Flame; this consists of four Flames in the Line *ll*; V V is the Glass represented by V, Pl. 109. Fig. 1; O O is the Picture in the small Glass Plane; *a a* the large Lense; *d d* a planer Lense; *b b* the wooden Ring between the Lense; *f* the Aperture of the Ring, that is, the Hole in the middle of it.

All these Things being plac'd, as has been already explain'd, and as is seen in this Figure; the Rays, which proceed from the Point of the Picture O O in passing through the Lense *a a*, diverge less, and come to the Lense *d d**, as if they proceeded from a more remote Point, out of which they go converging †, and are collected † upon the Surface of the white Plane, and make a Picture of that Point of the Figure in the Glass ‡; the Figure in the Glass is enlighten'd both by Rays proceeding from the Flame *ll*, and by Rays reflected from the Mirror S S.

In order to make this Machine perfect it is requisite, 1. That the Figure O O be enlighten'd as much as possible. 2. That it be enlighten'd equally in all it's Parts. 3. That all the Light by which

all the Points of the Figure are enlighten'd, pass through the Lenses aa , dd , to the white Plane, and serve to exhibit the Representation. 4. Lastly, that only this Light may go out of the Box, that the Representation may not be less vivid by Means of the extraneous Light.

3436. The first Thing requir'd depends upon the Magnitude of the Flame and the Speculum, as also the Concavity of it; the more the Speculum is hollow'd, the nearer O must it be mov'd to the Flame, and the Rays are intercepted in a greater Number, and reflected; but Care must be taken, that the Speculum does not grow too hot, which is best made of Glafs.

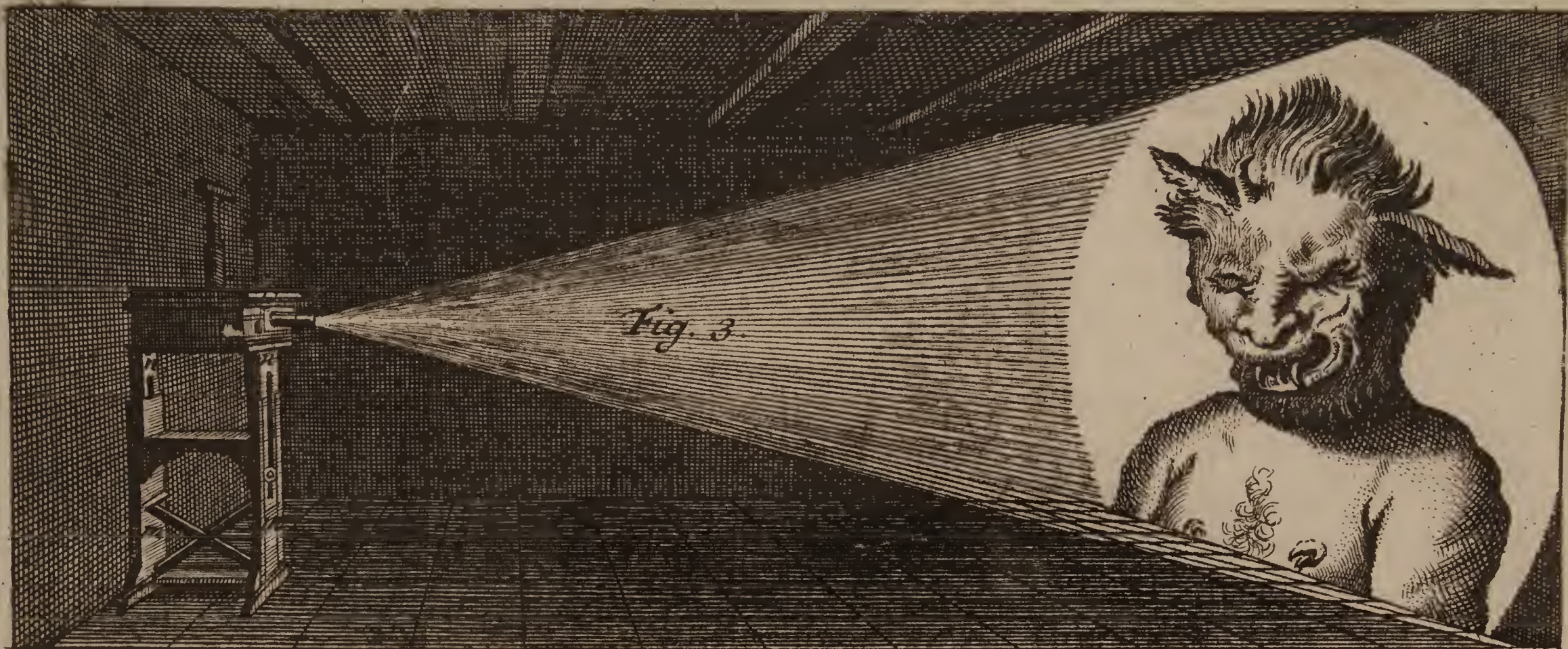
3437. But the Flame and Speculum being given, that the Picture may be enlighten'd as much as possible, and every where equally, the Flame and Speculum are so order'd, that the inverted Representation of the Flame * may fall upon the Picture itself: But as the Representation of the Flame may be increas'd and diminish'd †, the Speculum and Flame are to be so plac'd, that the Representation of the Flame may cover the whole Picture on the Glafs, and not exceed it. For then the Picture is illuminated as much as possible by the reflected Light, and all it's Pictures are equally illuminated; the Light also falls directly upon all the Points of the Picture; which is sensibly equal; the Flame being brought near, this Light would indeed be increased, but the reflected Light would be diminished; and this would be diminished more than that would be increased.

* 33 11.

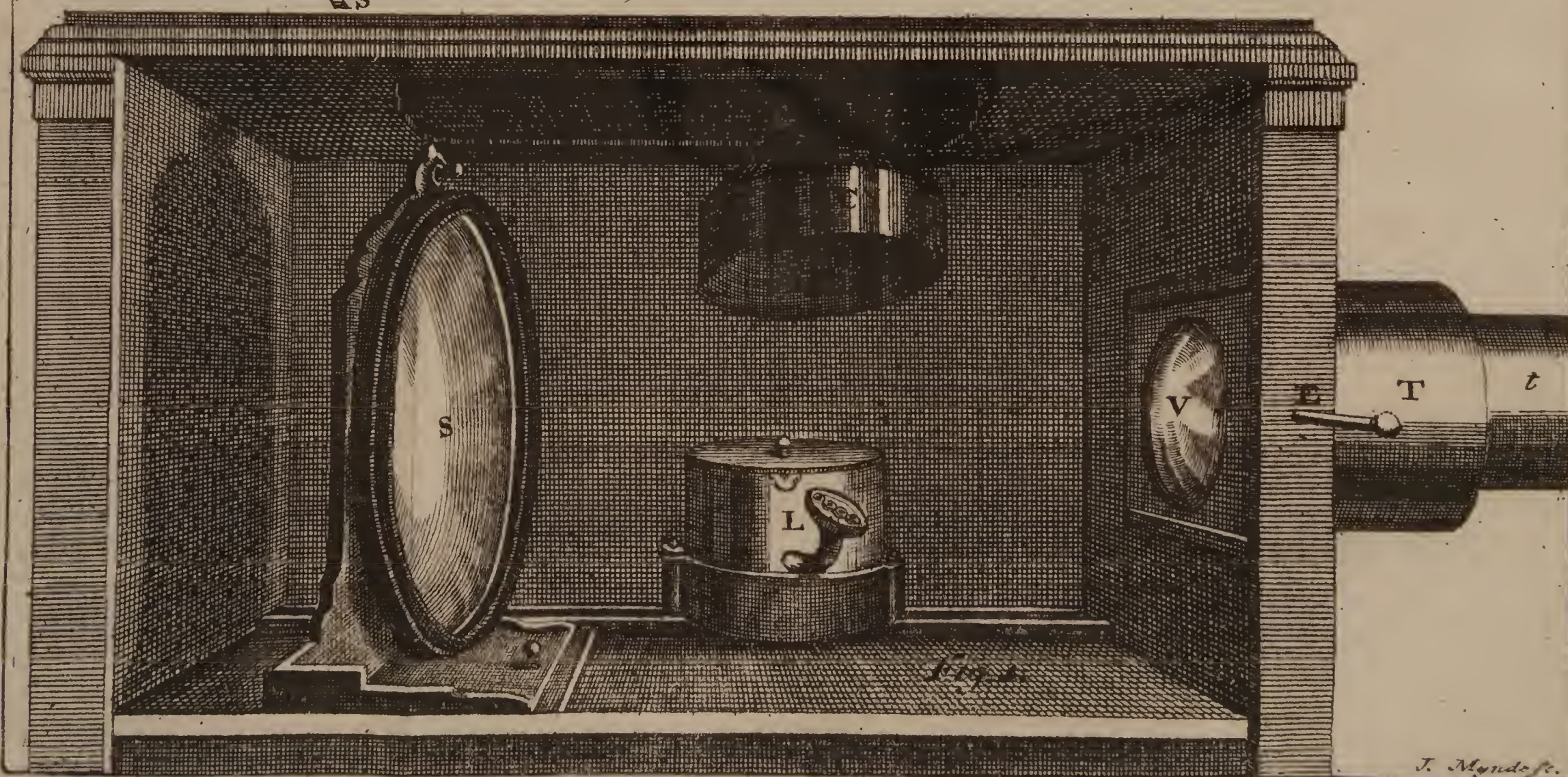
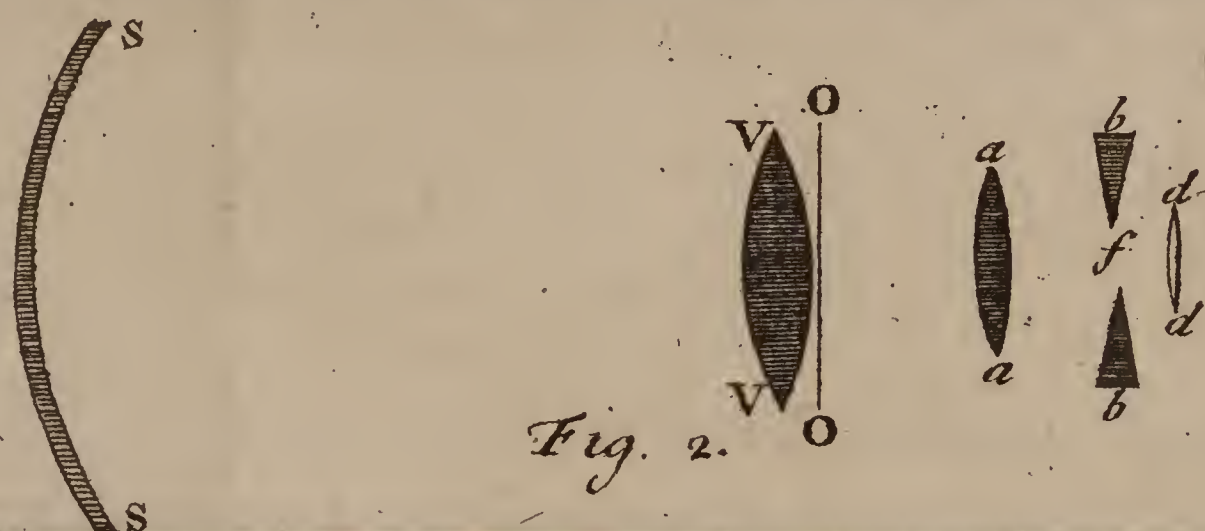
† 33 12.

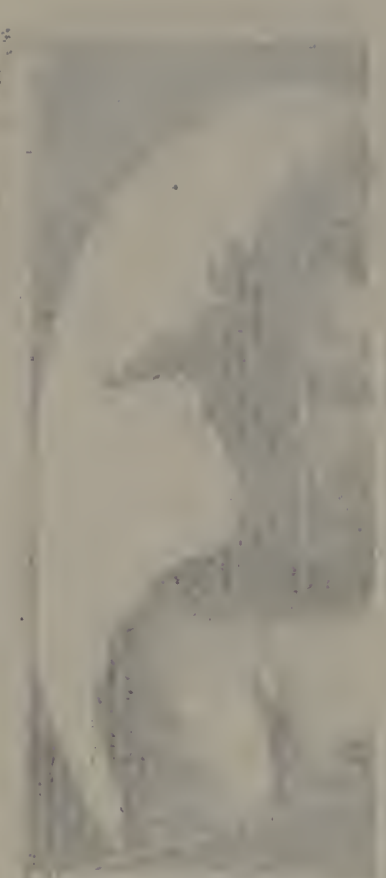
3438. The Use of the Glafs VV is to bend the Light with which the Picture OO is enlighten'd, before that comes to it, because by the Inflection all the Light comes to the Lense, aa , and is of use towards the Representation upon the white Plane.

3439. All the Light, which is of Service to this Representation, passes through the Hole f ; and the Rays proceeding from different Points mutually intersect one another; wherefore the Picture which is inverted upon the Glafs, appears erect upon the white Plane; all the Rays, which are of no Use to make the Representation, are intercepted by the Ring bb , that they may not enter into the Chamber and make the Picture less vivid. This Ring also intercepts the Rays, whereby one Point would be more enlighten'd than another, by which the Light, which is indeed equable enough, from what has been before said, becomes still more equable. Except the Ring bb be exactly in the Intersection of the Rays, it does a great deal of Harm.

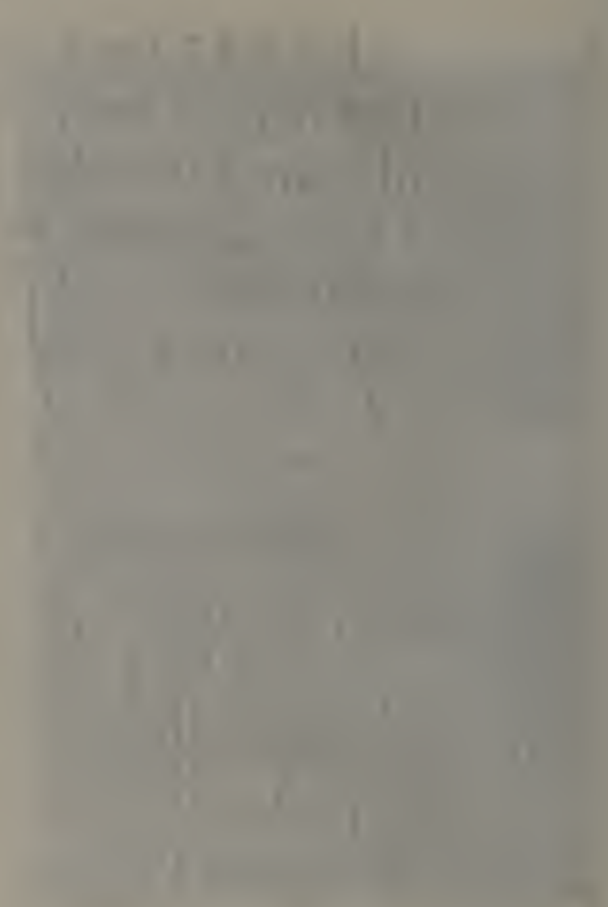


109





Small text label or caption located below the top-left image.



EXPERIMENT 2.

A Spectacle like that which we had in the first Experiment, is more conveniently and more distinctly represented in the Day Time, if the painted Figures be enlighten'd by Rays of the Sun. 3440.

A thick board H is applied to a Window, which stops a Hole in the Window-Shutter. At N there is an Aperture Q, which on Pl. 110. the outside is cover'd with thin Paper rubb'd over with Oil. F. 1, 2, 3. 3441.

To the Board N is applied M with it's Tube T in such manner, that the Interstice between the Rulers R P, R P, may answer to the Slits L I, L I (one of which only appears in the Figure) in the Rulers H G, H G; that the Frames together with their Figures may be conveniently mov'd along the Aperture Q. We put into the Tube T what was mention'd above *, and what was represented in Fig. 3. in which the Section of the whole Machine through the Axis is delineated; C C is the oil'd Paper; O O the painted Glass; the rest is explain'd above †, and mark'd with the same Letters here. * 3429. 3430. 3433.

When the Sun's Rays fall upon the Paper, the Figures are strongly illuminated, and are represented upon a white Plane, opposite to the Window, as in the last Experiment *. 3442. * 3432.

If the Paper be taken away, by reason of the Obliquity of the Sun's Rays, the Experiment does not answer well.

B O O K V.

PART IV. Of Opacity, and Colours.

C H A P. XIX.

Of the Opacity of Bodies.

3443. **T**HERE is no Body whose smallest Parts are not transparent ; Those who often use Microscopes do not in the least doubt of this : There are some Parts of Metals, which, though very small, do not transmit Light : Yet if they be divided in Menstruums ; that is, if they be divided into much lesser Parts, they will become transparent.

3444. The least Parts of all Bodies, that is, those which separate the ultimate or smallest Pores, are perfectly solid ; of these we do not here speak : But there are greater Parts formed by the Parts left by these Interstices, which are join'd together, greater Interstices remaining, and of which perhaps the greater Parts are formed, which Parts again may serve to form greater still, and so the Parts and Interstices between them have a farther Increase. When we speak of small Parts, we understand such as are exceeding little, whose Pores do not exceed a certain Bigness ; and by Pores we understand the greater Interstices in the Pores of those Parts which these Parts have between them.

3445. It is easily proved by an Experiment, that Light can pass through most opaque Bodies.

EXPERIMENT I.

3446. If in a dark Room, into which the Sun's Light comes through a Hole, the Hole be cover'd by a thin Plate of Wood, the Light will pass through it ; the Hand, when applied to the Hole, does not intercept all the Light. But this Experiment does not prove that the Parts of opaque Bodies are perfectly transparent ; for this only obtains in small Parts.

*Opacity does not arise, as is commonly imagined, from the Stoppage of the Particles of Light by Particles of Matter; for Light passes through all the smallest Parts of Bodies; nor is such an Interception of Light of any Use in causing Opacity; for this it is required that the Light be reflected and deflected from a Right Line, in the Performance of which there is only required a Separation of two Mediums *.*

3447.

* 3247. 3260.

Let us suppose a Body consisting of very small Parts perfectly transparent, such as are the Particles of which Bodies are made †, separated from one another by Pores; and that those Interstices are either void or fill'd with a Medium differing in refracting Force from that of the Particles; if Light enters such a Body, it will every Moment fall upon a Surface separating Mediums of a different refracting Force; and therefore it will undergo innumerable Reflexions and Refractions * in that Body; and it is so dispersed in the Body, that it is easily all intercepted. Some of it often passes through, but the right lined Motion is entirely disturb'd †.

3448.

† 3438.

* 3247. 3260.

† 3445.

We see therefore that *Opacity depends upon the Pores; for if you fill the Pores with a Medium of the same refracting Force as the Particles of the Body themselves, the Light will undergo no Reflexion or Refraction in the Body, but pass directly through; and the Body will be transparent.*

3449.

EXPERIMENT 2.

If Paper be moisten'd with Water, it becomes more transparent, for it fills the Pores, and differs less in refracting Force from the Particles of the Paper than Air does. Oil produces the same Effect.

3450.

EXPERIMENT 3.

Take a Piece of Glass, two Inches thick; take several Plates of the same Glass, which being laid upon one another, are not altogether quite two Inches thick; these, though they are smooth on each Side, will be less transparent, than a Piece of Glass, whose Parts all cohere together, because of the Air that is between the Plates.

3451.

EXPERIMENT 4.

Take three Plates of such Glass of which Speculums are made, placing them upon one another, whose four Surfaces, which are apply'd to one another, are made rough by rubbing Sand upon them;

3452.

them; the two outward Surfaces are smooth. These Plates are opaque. If they be apply'd to Paper, upon which Letters are written, or upon which Figures are drawn, we perceive nothing of them. If the said rough Surfaces be then anointed with Oil of Turpentine, and they be again applied to one another in the same manner, the Figures, which are cover'd with the Glasses, appear distinctly enough. But the Glass Plates are not perfectly transparent, the Oil of Turpentine does not exactly agree with the Glass in it's refracting Force; in the Passage of Light out of the Oil into the Glass the Sines of Incidence and Refraction are nearly as 60 to 59.

3453. But we see plainly how Bodies become transparent, in the first
 * 2845. Experiment of the sixth Chapter of this Book *, because the Oil of Olives has the same refracting Force as the Borax, of which many Pieces may be used.

3454. What has been said about Opacity is farther confirmed, and put out of all Doubt by innumerable Experiments, by which *Bodies perfectly transparent become opaque by the Separation of their Parts*, without the Intervention of any opaque Body.

EXPERIMENT 5.

3455. Let any Liquid perfectly transparent, which may be changed into Froth, be agitated till it be full of Bubbles, it will immediately become opaque, because the Interstices are fill'd with Air.

EXPERIMENT 6.

3456. Turpentine and Water are transparent Bodies; but if they are mixed, they form an opaque Body.

EXPERIMENT 7.

3457. Water and Oil, by being mix'd, become opaque; though when separate they are transparent.

EXPERIMENT 8.

3458. Glass, though never so transparent, when reduced to Powder, becomes opaque. So likewise it does when it is cracked.
3459. In all these Cases we clearly see that Opacity is produced, because there is a Medium of a different refracting Force between the transparent Parts; which also is observ'd in the Clouds, which are opaque, because of the Air's Interposition among the Particles of Water.

Chap. 20. of Natural Philosophy.

239

If to these we add, what is said in what follows, concerning the Colours of thin Plates; we shall have new Experiments, by which it is fully proved that Bodies intercept Light, because they consist of thin Particles, encompassed with a Medium differing from them in refracting Force.

3460.

Some opaque Bodies reflect a little Light, and the Light remaining is by the innumerable Divisions, which it undergoes in the said Reflexions and Refractions, extinguished in the Body; such are black Bodies; if there were any *Bodies perfectly black*, they would reflect no Light at all; for all Bodies, when no Light falls upon them, and they reflect no Light, appear black.

3461.

3462.

Other opaque Bodies appear of several Colours; some transparent Bodies are also ting'd with Colours: Whence these arise we shall now examine.

3463.

C H A P. XX.

Of the different Refrangibility of the Rays of the Sun, and their Colours.

BODIES appear differently colour'd, though they be enlighten'd by the same solar Rays, that are reflected by them: There are besides several Phenomena of Light with regard to Colours, which must not be passed by.

In these three Things are to be observ'd: 1. The Rays must be examined, as they flow from the Sun. 2. Their Reflexion must be observ'd. 3. We are to enquire into the Make of the Surfaces of Bodies differently colour'd.

3464.

As to the Rays, the first Property to be here taken Notice of, is, that *all Sorts of Rays do not suffer the same Refraction under like Circumstances.*

3465.

DEFINITION I.

The Rays which undergo such a different Refraction, are said to have a different Refrangibility, and those to be more refrangible, which are more inflected by Refraction.

3466.

DEFINITION 2.

Those Rays are said to be homogeneous which do not differ from one another in Refrangibility.

3467.

DEFINITION 3.

3468. *All those are called heterogeneous, which are not equally inflected by Refraction under the same Circumstances.*

3469. Let there be a Sun-Beam between A B and C D, made up of an innumerable Number of parallel Rays; all these do not suffer an equal Refraction; for if they fall obliquely upon the Surface B D of the more refracting Medium, some of them are refracted between B E and D G, and are moved according to that Direction in the Medium; others are more inflected, and direct their Motion between B F and D H, in the Direction of those Lines; nor can there be conceiv'd any intermediate Direction, along which some Rays do not move, in all the Points B and D: So that the least Ray whatsoever is by Refraction, divided into innumerable other Rays; because every Ray, as it proceeds from the Sun, though never so small, is heterogeneous, and consists of innumerable Rays of all Degrees of Refrangibility.

The parallel Rays aforesaid, falling upon the plane Surface B D, are moved between B E and D H by Refraction; which Lines diverge more and more from each other, and, being continued, are more and more separated; so that the Rays abovemention'd are

3471. dispersed by Refraction. In N. 2859 we have consider'd the Rays as homogeneous, as also every where in the second Part of this Book;

* 3222. we have taken notice of a different Refrangibility in one Case only; the Difference of the Refrangibility in the Sun's Rays is so small*, that it might have been neglected in what has been already said. What happens to homogeneous Rays was also first to be examin'd; and what Alterations are to be made in the Propositions, by reason of the different Refrangibility, will easily appear to every Body.

3472. In order to make the different Refrangibility of Rays visible, the Divergency aforesaid must be increased; which will be done, when the Rays abovemention'd fall upon the Surface E H, which terminates the more refracting Medium, and separates it from the less refracting Medium, and which makes any Angle with the Surface B D, but less than eighty Degrees, if Glafs be used; but the Surface E H is so inclin'd to B D, that the Rays, which are more refrangible, fall more obliquely upon it than those that are less refrangible; so that the former, in passing into the less refracting Medium, are more turned out of their Way, and diverge more from the others, for two Causes, the greater Refrangibility, and the greater Inclination. The less refrangible Rays continue their Motion between B E and D G, being refracted a second time, they continue

continue their Motion between E I and G L, the others between F M and H N: In which Case if these Rays fall upon a Plane, at the Distance of fifteen or twenty Feet, the most and the least refrangible Rays are sensibly separated, and the whole intermediate Space is enlighten'd with Rays that have a mean Refrangibility; which is shewn by Experiments made with a triangular Glass Prism through which a Ray is transmitted perpendicular to the Axis, and whose Sides are represented by the Lines B D and E H.

But the Experiments that are of use here, are to be made in a dark Place, the Light being let in through a narrow Hole, as in the Experiments of the third Chapter of this Book; sometimes we also make use of two Holes together. We have before said what we must do when the Heliostate is made use of*. We have also shewn how to proceed, when these Experiments are to be made without it*; but I will now explain it more clearly,

In Window-Shutters a square Aperture is made whose Side is four or five Inches, which is clos'd by a Board, as T, which is moveable between Rulers, that it may be changed, because several are required.

In this which is now exhibited there is a Hole whose Diameter is equal to three Quarters of an Inch; this is hollow'd behind, that the Object Glass of a Telescope may be put into it upon Occasion. The Board T is also hollow'd a little before, that a thin round Plate of Brass may be put into it, which is perforated, but not in the middle; and the Hole in this Plate answers to a Hole in T. To this Plate is joined another smaller concentric Plate *m*, which is moveable about a Center. In this there are several unequal Holes, which whilst the little Plate is turn'd round pass into *f* in such manner, that Light may be let into the Chamber through a greater or less Aperture, at Pleasure.

When the Rays are to be let in through two Holes, we make use of another Board; in which there is a greater circular Aperture, which is closed by a brass Plate; this turns about in that, that the Position of two Holes, which are in this Plate, may be alter'd.

We may also make use of this Method, we close the square Aperture in the Window-Shutters by the brass Plate T, whose fore-part is represented at *t*; in which we have mark'd the Magnitude *a, b, d, e*, of the said Aperture. The Shutters are made hollow, to receive the Plate T, which is fasten'd by Means of the small Buttons *b, b, b*. In the Middle there is a Hole *f*, and at the Angles there are four others *g, g, g, g*, whose Diameters

are three Quarters of an Inch; but which may be varied, and clos'd, by the Plates m, n, n, n, n , which turn upon the Centers c, c, c, c, c .

3478. When the Object Glass of the Telescope, which has been
* 3475. mention'd above *, is to be made use of, this is retain'd between the Screws i, i, i .

3479. In the following Experiments we make use of Prisms which
* 3249. turn about their Axis, spoken of above *.

3480. Such a Prism $A B$ is put upon a Stand, which is represented at
Pl. 110. S . The Prism may be laid upon the Stand at different Heights, and fasten'd by Means of the Screw C .

Fig. 7. 3481. The Prism may be also put into a vertical Position, then the prominent Part at B is put into the Hole b , and the Point C is put into the Slit a , and the Prism may be fasten'd by the Screw.

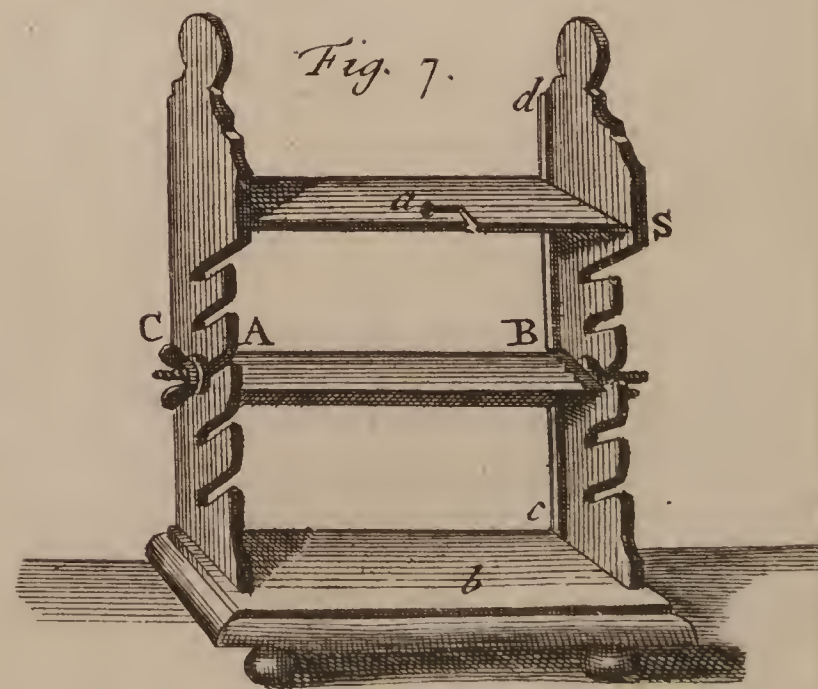
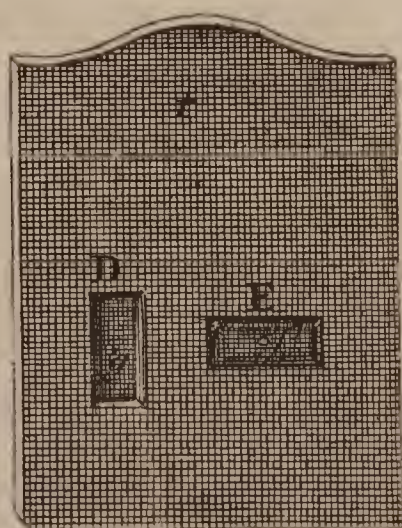
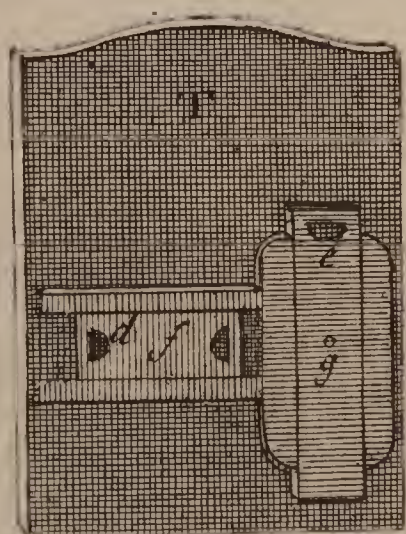
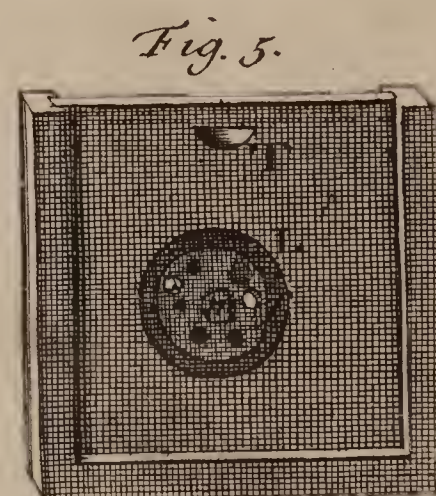
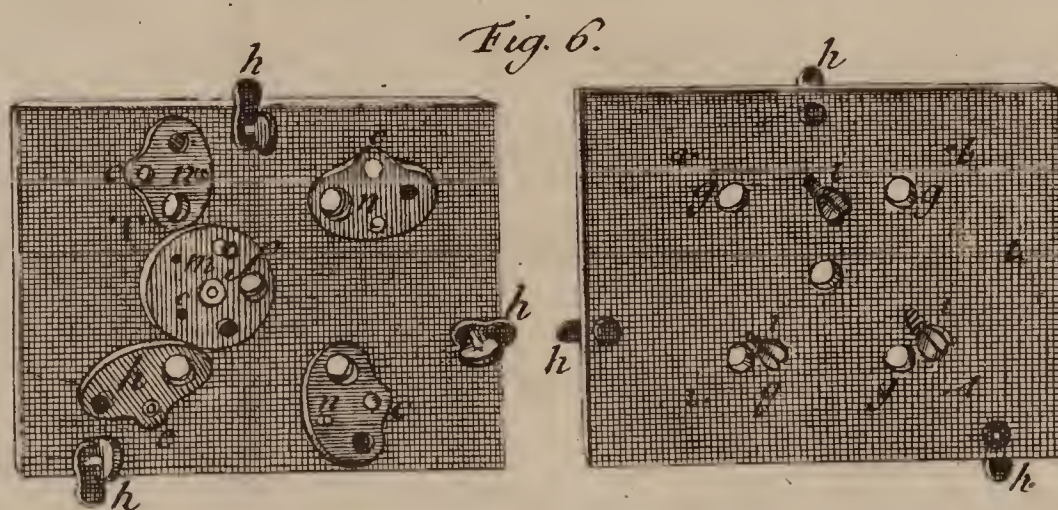
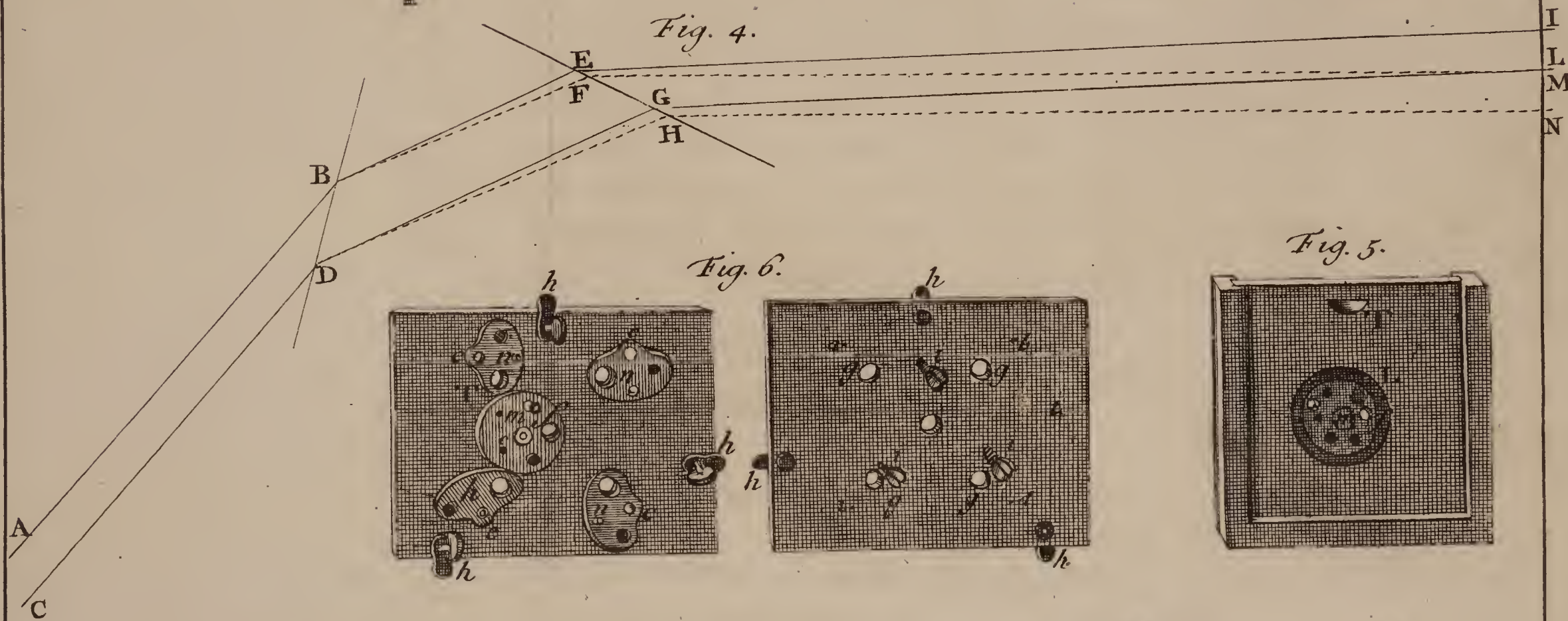
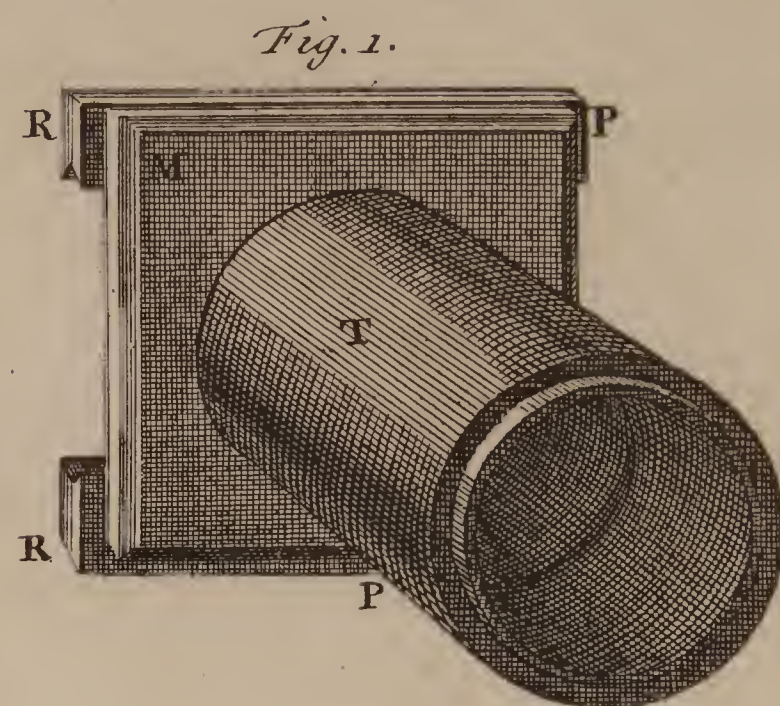
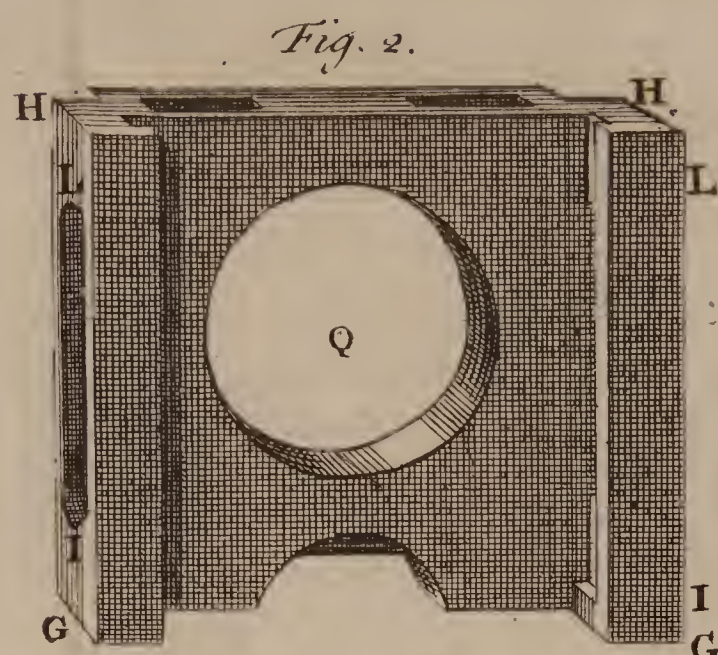
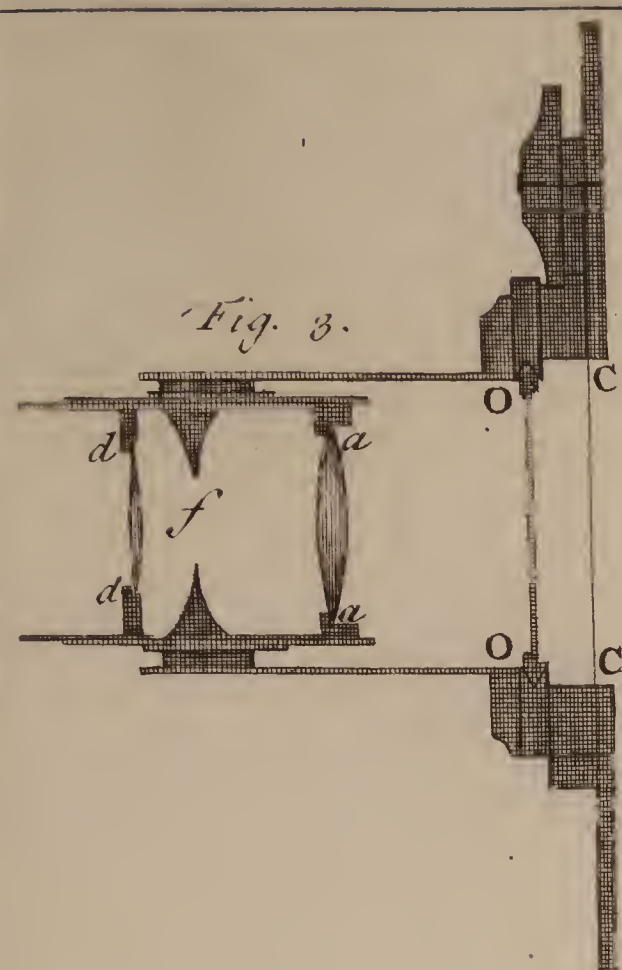
3482. To this Stand is join'd the Board T going into the Groove d, c ,
Pl. 110. and another like and opposite to this; the Face t of this Board is turn'd towards the Prism. In this Board there are two Apertures D and E , which are clos'd by the Rulers d, e , which move between other smaller Rulers; those Rulers are perforated at fg ; and the Diameters of the Holes do a little exceed the eighth Part of an Inch. Sometimes two and also three Stands are requir'd; but in the others it is sufficient, if the Prism be fix'd at one Height only, and indeed that which is here represented; it is also sufficient if two of the Stands have Boards.

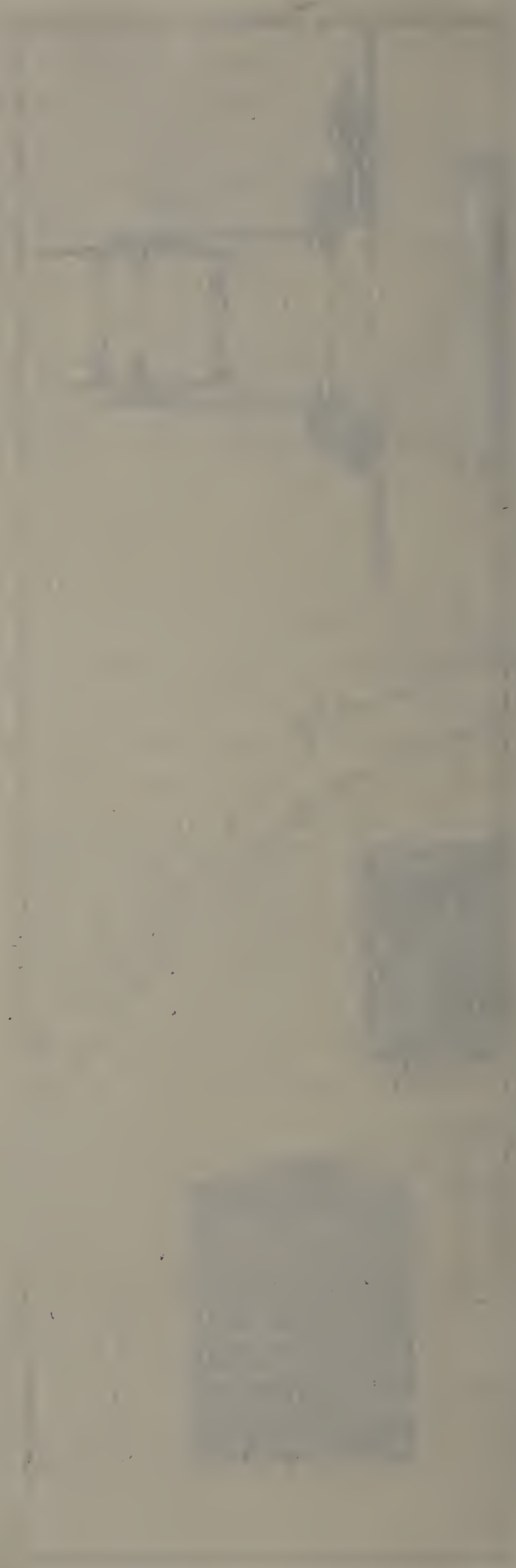
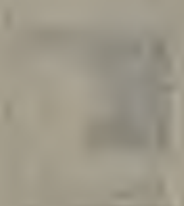
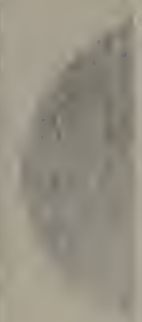
EXPERIMENT I.

3483. A Ray is let into the Chamber and directed upwards in such
Pl. 111. manner, that it may make an Angle of about forty Degrees with the Horizon, but the Diameter of the Hole through which the Ray passes does a little exceed a quarter of an Inch. The Ray is transmitted through the Prism P , which is laid upon the Stand S *,
* 3480. which stands upon the moveable Table M †, that it may be raised to the Height requir'd. The Ray is directed perpendicularly to the Axis of the Prism, which is so plac'd, that the Ray may pass through in the same manner as is represented in Figure 4, Plate 110; that is, that it may be equally inclin'd to each Surface of the Prism.

3484. This Ray falls perpendicularly upon the white Paper T , extended upon a wooden rectangular Limb, which coheres with the Stand P ,
* 2775. and may be raised and depressed and fix'd at the Height required *. But as the Ray, in passing through the Prism, is disperfed, it makes an oblong Image, which that it may be distinctly perceiv'd, the

Paper





Paper should be remov'd to the Distance of sixteen or twenty Feet from the Prism.

We determine the requir'd Position of the Prism, and which was shewn above, if the Prism be turn'd about it's Axis a little, in such manner, that the Image may ascend, which afterward descends, if the same Motion be continued; but the Prism must be fix'd, when the Image comes to the greatest Height, before it descends again.

3485.

How this oblong Image is made, is deduced from what has been explain'd before *, but I shall now explain it more distinctly.

* 3472.

Let C be a Point of the Plane, parallel to the Hole, against which a Ray strikes, which passes from the Center of the Sun through the Center of the Hole, which we suppose circular. All the Rays, which, proceeding from the other Points of the Surface of the Sun, intersect the first Ray in the Center of the Hole, and run against the Plane, make there an Image of the Sun *a, b, d*, whose Diameter, the Plane being remov'd ten Feet from the Hole, would exceed one Inch, and which would be increased in the Ratio of the Increase of the said Distance.

3486.

Pl. III.

Fig. 2.

The Rays, which pass through all the Points of the Hole, give a like Image; and the Centers of them all are in a small Circle equal to the Hole itself, for all the Rays proceeding from the Center of the Sun are taken for parallel. Therefore all the Images together make the Image *ABD*, which is weaken'd near the Limb, and whose Diameter exceeds the Diameter of the said Image by a Quantity equal to the Diameter of the Hole.

If all these Rays were homogeneous, as they are in the last Experiment, equally inclin'd to the Surface of the Prism, in the Ingress and Egress, the Direction of all of them would be only chang'd, and they would make a like white Image upon the Plane. But they are heterogeneous that pass through the Prism, and the most refrangible ones give the Image *a b d e*, which in the Experiment is more depressed; whilst the least refrangible Rays make the Image *ABDE*. The Rays of intermediate Refrangibility give intermediate Images, whose Centers take up the whole Line *C c*. These Images jointly make the oblong Image represented in the foregoing Experiment; and except there were innumerable such Images, the Image would not be terminated towards the Sides by Right Lines; but although this Image is terminated toward the Sides by Right Lines, yet the Terms are not distinct; because the peculiar Images are not in the Form of a Circle *: But at the Extremities *A* and *e* the Light is

3487.

Pl. III.

Fig. 5.

* 3486.

weaken'd through the whole Semi-circle, and these Terms of the Image are confus'd.

But we easily have an Image distinctly terminated towards the Sides.

EXPERIMENT 2.

3488. The Object Glass of the Telescope beforementioned * is fix'd in
* 2706. 3475. the Hole, and this Experiment differs from the last in this Circum-
3478. stance only. For Paper, or a white Plane, being plac'd at a just Distance, the Image is terminated distinctly.

3489. For if, the Prism being taken away, the Image of the Sun falls upon the Plane, and the Plane be remov'd from the Glass to a Distance at which the Glass collects parallel Rays proceeding from all Points of the Sun's Disk, there will be given a round Image of the Sun, as we have seen of other Objects *. When the Rays pass through the Prism, the Image is made oblong from innumerable Images well terminated.

* 3060. What has been seen concerning the different Refrangibility in Glass is in the same Manner observ'd in other Mediums.

EXPERIMENT 3.

3491. The Box P is made of three Glass Plates, whose Bottom is of
Pl. 111. Brass; this is constructed, as has been seen above *; the Angles,
Fig. 4. which the Planes make, are of 50, 60, and 70 Degrees.

* 2759. Any Fluid is pour'd in, as Spirit of Wine, Oil of Turpentine, &c. and a triangular Prism is made of the Matter pour'd into the Vessel, whose Figure this puts on.

3492. We have Occasion for a Ray of the Sun let into a dark Place, in this Experiment, as in the foregoing ones; but it's Direction must be horizontal.

This is transmitted through the Prism, or Box mention'd, which if it be empty, the Light passes through in a strait Line, but if it contains a Fluid, it is bent, as has been seen above *. The Prism is disposed in such manner, that the Light may be equally inclin'd to each Surface through which it passes †; and the Light, if it falls upon a vertical Plane plac'd at the Distance of sixteen or twenty Feet from the Prism, will give an oblong Image, as in the foregoing Experiments, but horizontal, whose Length will be different, according to the different Angle, which the Surfaces make, through which the Light passes, and according to the different refracting Force of the Fluid, contain'd in the Prism.

* 3472.

† 3485.

EXPERIMENT 4.

Let there be a Spectator at the Distance of sixteen or twenty Feet looking at the Hole, through which the Light is let into the Chamber, that appears round; if the Observation be made through a Prism, in such manner, that the Rays proceeding from the Hole, come to the Eyes, after Refractions, like those which the Light undergoes in the mention'd Experiments, the Hole will appear oblong. The Position of the Prism is found, if, this being put into a horizontal Position with the Edge uppermost, in such manner, that the Hole be rais'd, it be turn'd about it's Axis a little, with which Motion the Image of the Hole ascends and descends, and the Prism be kept in the Position, in which the Hole appears rais'd least of all. The Prism may also be put into a contrary Position. 3493.

This Experiment, as well as the foregoing, proves the different Refrangibility of Rays; for, by homogeneous Rays of any Refrangibility, the Hole appears remov'd out of it's Place, but circular.

The Rays, which undergo a different Refraction, enter the Eye in different Directions, and different Images are given, which join'd make an oblong Image, which is really seen.

Besides the different Refrangibility of the Rays, the foregoing Experiments also shew another remarkable Difference between the Rays. 3494.

The different Refrangibility of the Rays is join'd with a different Colour; and all the Rays, as they are more or less bent by Refraction, have a Colour peculiar to themselves. 3495.

With Regard to Colours it must be observ'd, as has been already observ'd * concerning other Sensations, that they are Perceptions, * which have nothing common with the Rays, whereby they are excited; therefore we must give a Definition, what we understand by colour'd Rays, and colour'd Objects. 3496. 23 10.

DEFINITION 1.

An Object is said to be ting'd with that Colour whose Idea is excited in the Mind by Rays reflected from the Object. 3497.

DEFINITION 2.

Homogeneous Rays which strike against the Retina and excite in the Mind an Idea of any Colour, are call'd Rays of that Colour. 3498.

We say that Rays excite the Idea; that is, that Rays move the Fibres, and that when this Agitation is given, the Idea is present to the Mind. 3499.

We

3500. We find the Colours of Rays immediately in *the oblong Image of the Sun* often mention'd; for this Image is *ting'd with different Colours*.

3501. *The Rays that are least turn'd out of the Way by Refraction, are*
Pl. III. *red Rays; the rest of the Colours follow in this Order; orange, yellow,*
Fig. 3. *green, blue, purple, violet, the Rays of which last Colour have the*
greatest Refrangibility.

3502. The oblong Image of the Sun, as has been said, is made of in-
* 3487. numerable round Images *: If the Diameters of them be dimi-
nish'd, which is done by intercepting the Rays of the Sun in such
manner, that those only may pass through the Prism, which come
from a small Part of the Surfaces of the Sun, the Centers of the
peculiar Images making the oblong one are not alter'd; therefore
the Length *ab* of the Image between the parallel Lines is not
alter'd. And this only would remain, if the Breadth of the Image
should be infinitely small, and this Length only were to be consider'd
in determining the Limits of the Colours in the Image. These
are mark'd in the Figure by the Letters *a, b, c, d, e, f, g, h*, and
the Number wrote against every Colour denotes the Space taken up
by it in the Image, the whole Length of the Image being divided
into 360 Parts.

3503. *The Rays in the oblong Image are indeed separated; nevertheless*
every where many peculiar circular Images are confused, and
they are no where perfectly homogeneous.

3504. *When the Breadth of the Image is diminished by the Method just*
* 3502. *shewn *, all the Circles become smaller and are confused by a*
smaller Number, and those, which are confused, differ less in Re-
frangibility; wherefore in the whole Image the Rays are more homo-
geneous, and the Colours more perfect; and likewise weaker.

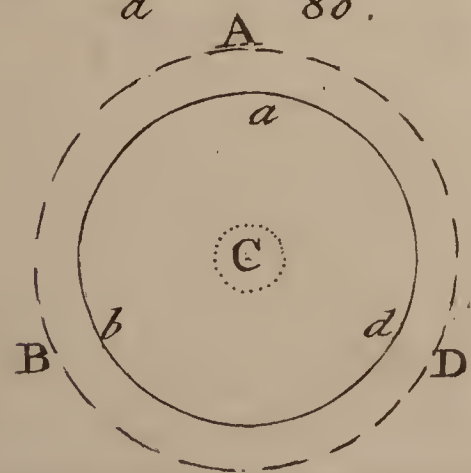
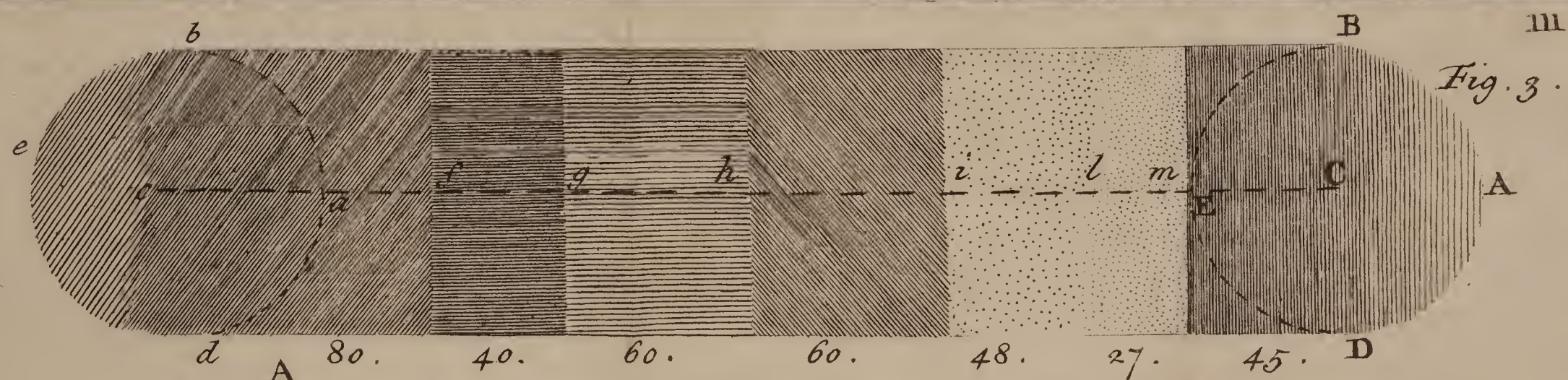
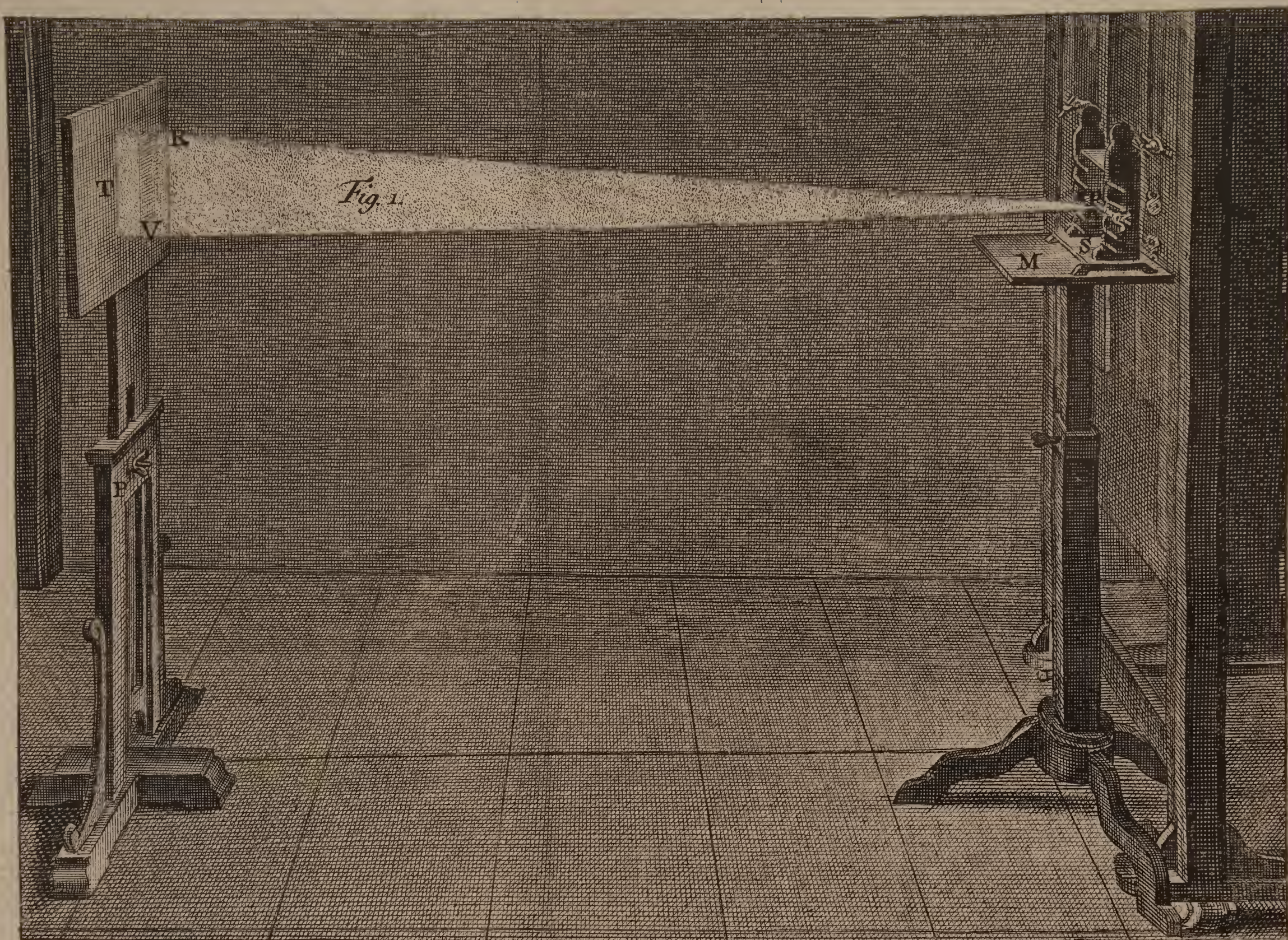
3505. The Colours in the Image are also more perfect, the smaller the
Hole is, through which the Rays are let in; because the Number
* 3486. 3487. of the Images, which are every where confused *, is diminish'd,
and they have a different Refrangibility; the Image is also weaken'd.

Nevertheless the Colours become but a little more perfect by this
* 3502. Method, the first is to be prefer'd *.

3506. But if we would have the Colours more lively, and at the same
Time more homogeneous, we have them in the following Expe-
riment.

EXPERIMENT 5.

3507. Rays proceeding from the Sun are let into a dark Chamber through
Pl. II. 2. a Hole, whose Diameter is equal to about the eighth Part of an
Fig. 1. Inch;



Inch ; the Direction of these is horizontal, and at the Distance of eight Feet from the Hole they fall upon the convex Lense L, which collects parallel Rays at the Distance of four Feet ; if these Rays run against a white Plane at the same Distance of eight Feet from the Lense, they will give an Image of the whole equal to it *.

* 3035.3045.

But if the Rays behind the Lense be intercepted by the vertical Prism P *, they are bent, and dispersed †, and make the colour'd * Image R V ; by turning the Prism about it's Axis the Position of † the Prism is sought, in which the Rays are least bent, and fasten'd ‡, ‡ the Paper T * is plac'd, that the Light may fall upon it perpen- * dicularly ; and it is removed till the Image be circular.

3508.

3481.

3484.

3485.

3484.

This Image has but a small Breadth, because it consists of Images equal to that mention'd * ; it is vivid, and as the homogeneous * Images are confus'd in a smaller Number ; the Light is every where less heterogeneous than in the foregoing Experiments.

3509.

3507.

We have an Image equally pure, but more broad, if the Light passes through a vertical Slit, above an Inch high, and whose Breadth is equal to the Diameter of the Hole which has been made

3510.

Pl. 112.

Fig. 2.

use of in the Experiment. The Slit may be also narrow'd more, and then the Light is every where more homogeneous in the Image, which now makes a Parallelogram, whose Breadth is equal to the Height of the Slit. If this Slit have the Figure of an Isosceles Triangle whose Base compar'd with the Height is small, the Image throughout it's whole Length is more vivid near one Side, and is weaken'd towards the other ; because the Slit is narrow'd towards that Part, through which the Rays pass : Therefore the Light is also more homogeneous, in the Ratio, in which it is weaken'd.

3511.

The Demonstration, before given *, concerning the constant Ratio between the Sines of the Angles of Incidence and Refraction, must be referr'd to all homogeneous Rays ; for it is not confin'd to any certain Degree of Refrangibility ; but this Ratio varies, according to the different Refrangibility ; as clearly follows from the Experiments of this Chapter.

3512.

* 2809.

But that *Refrangibility and Colour in all Rays are entirely unchangeable* ; that is, that they are not alter'd by any Refractions, Reflections, or Permixonions, plainly appears from Experiments to be shewn in the three next Chapters.

3513.

C H A P. XXI.

That Rays are not alter'd by Refraction.

3514. **W**E shall now demonstrate by Experiments, that *the different Refrangibility of Rays is inherent in them, as also their Colour*, and that these Qualities do not depend upon a refracting Medium, from which Experiments it will appear; that *the Rays, which in one Case undergo the greatest Refraction, are most turn'd out of their Way in any other Refraction whatever*,

EXPERIMENT I.

3516. A Ray, as in the first Experiment of the last Chapter, is let
 Plate 112. through a Prism, this is dispersed, and divided into many Rays,
 Fig. 3. which would make an oblong Image, if they fell upon a white
 * 3484. Plane *; but they are intercepted by the vertical Prism C D, plac'd
 at any Distance from the first Prism; but the less the Distance is,
 the more sensible is the Experiment.

The Rays in passing, through this second Prism, are bent sidewise, and the Prism being mov'd, till the Deflection is the greatest of all, let it be fix'd; and let the Rays fall upon white Paper perpendicularly.

3517. The Rays are now refracted by the second Prism in the same manner, as by the first, but they are not dispersed in the same manner, which would give a square Image; but this is inclin'd at R V, the Rays being turn'd out of their Way most at V, as in the Refraction through the first Prism.

3518. There is also another different Refraction of the Rays, not depending upon the Rays, but the Medium. Chrystals and transparent Flints, though I can't say all, have this wonderful Property, that they divide in Refraction every homogeneous Ray into two; which Separation is different not only in different Bodies, and in different Inclinations of the Rays; but it is also different in the same Body, and the same Inclination, according to the different Position of the refracting Surface, and the refracted Ray, with respect to the Vein of the Stone; but neither the Colour nor Refrangibility are alter'd by such a double Refraction, and Division of Light.

EXPERIMENT 2.

This Experiment was made with a very pure Prism, sent from *England*, made of a *Brasil* Pebble. 3519.

This Prism is equi-angular, and the first Experiment of the last Chapter being repeated with this Prism, instead of the Glass Prism, and this being plac'd in such Manner, that the Axis might be horizontal; I observed three different Phenomena, according to the different Angle, that was upwards: A double Refraction was always discover'd, and two oblong Images were perceiv'd; but they were not separated.

In the first Position of the Prism the upper Part of the Image was painted with a pure red Colour, the lower with a violet Colour, in the whole intermediate Space, it appear'd that there are the same Colours, which we had before, but these were confused and mix'd together, so as they shew'd, that there were two colour'd Images, which did not agree. 3520.

In the second Position of the Prism, the Images did less agree, and the red Colour of the upper Image was separated more, as likewise the violet Colour of the lower Image, and that Image was longer. 3521.

In the third Position of the Prism the Image was extended very much, and they were both separated more, so that the red Colour was entirely rais'd above the lower Image, and likewise the orange Colour, and part of the yellow Colour of the upper Image; whereby it happen'd also, that the violet Colour, and Part of the Purple, of this Image was separated; the rest of the whole Image was very much confused. 3522. Plate 112. Fig. 4.

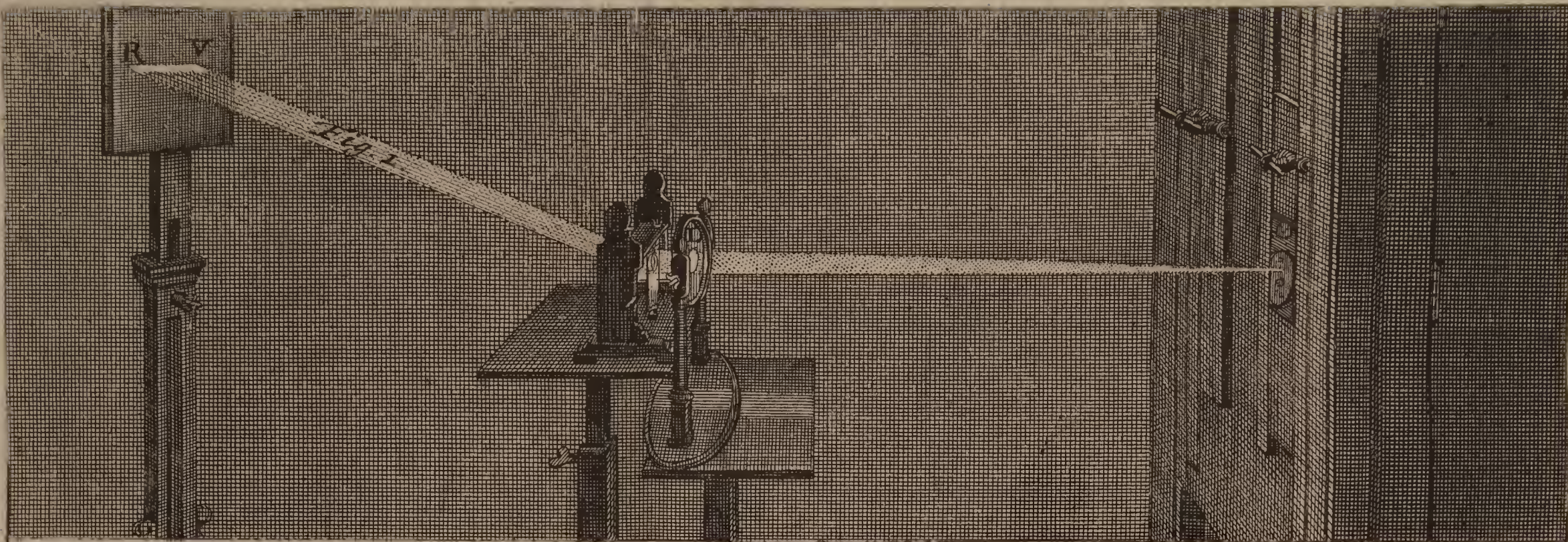
The Prism remaining in this Position, I transmitted Rays, going out of this, through the vertical Glass Prism, as in the last Experiment *. By this Refraction they were inclin'd, and quite separated. * 3523. 3516.

These Images were parallel, and the Colours in the vertical Lines corresponded, and indeed in such manner, that it appeared, that the red Colour of each Image was the least bent of all in the second Refraction, and equally in both Images. So also the two violet Colours had the same Refrangibility, and the greatest of all. 3524. Plate 112. Fig. 5.

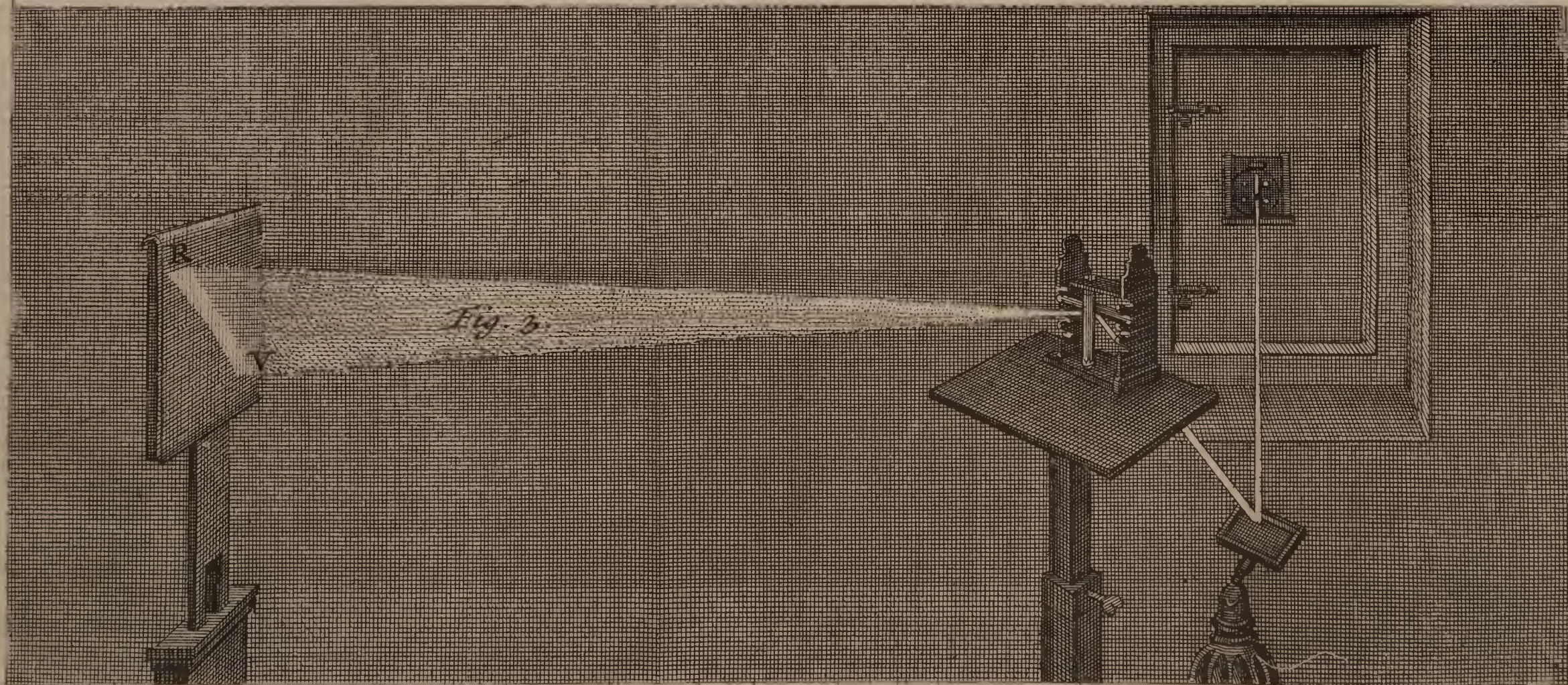
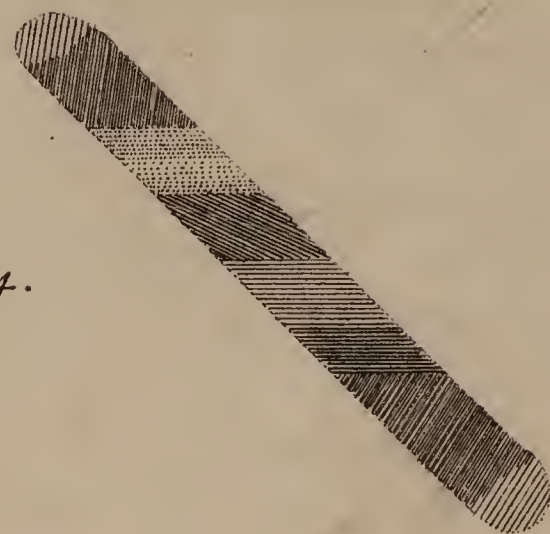
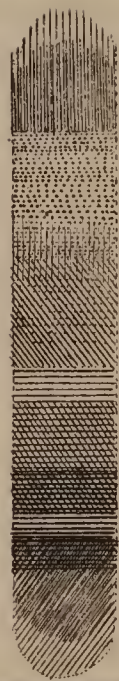
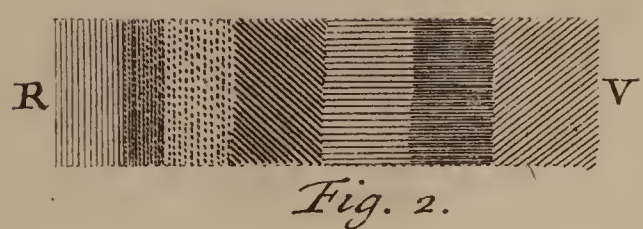
Although it is manifest enough from these Experiments, that Colour and Refrangibility are not alter'd, which is also confirm'd by many Experiments, hereafter mention'd; nevertheless I will add one Experiment more, which has been made by many without Success, but which always succeeds, when due Caution is used. 3525.

EXPERIMENT 3.

3526. A Ray of Light is transmitted through the Prism, as in the first
 Plate 113. Experiment in the last Chapter ‡; but the Hole, through which
 Fig. 1. the Light enters, is greater, and it's Diameter exceeds half an Inch:
 ‡ 3483. The Light, whilst it goes out of the Prism, falls upon the Surface
 * 3482. of the Board T*, which intercepts the Rays, those only being left,
 † 3482. which go through the Hole g †. These are not yet separated;
 because this Hole is at a small Distance from the Prism: Yet they
 are dispersed, and the oblong Image R V, falls upon the Board
 ‡ 3482. join'd to the Stand of the second Prism ‡, at the Distance of ten or
 twelve Feet: Which Stand is so plac'd that the Hole g, which
 corresponds with g, is in the Image itself, and some of the Rays
 pass through it, which fall upon the second horizontal Prism, by
 whose Refraction they are directed downwards or upwards, as in
 this Figure, and fall upon the white Paper. By moving the first
 Prism a little about it's Axis, the Rays of all Colours go through
 the Hole g successively, and are refracted by the second Prism.
3527. In this second Refraction there is no Dispersion of the Rays;
 the Images, when the Paper is inclin'd, so that the Light falls upon
 it perpendicularly, is round, and of one Colour; namely of that,
 which passes through g; the Refrangibility also in this Case is not
 alter'd, and the Spot S changes it's Place in such manner, whilst
 the Colour is alter'd, that it appears that the red Rays are refracted
 least of all, the violet Rays most of all.
3528. This Experiment may be varied, and made with vertical Prisms,
 in this Case, the Ray, which falls upon the first Prism, must be ho-
 * 3482. rizontal; then the Holes f and f* are to be made use of, which
 are in Plates that may be moved horizontally.
3529. The first Prism remaining also, and the Light being transmitted
 through the Hole g, a second Prism may be plac'd vertically, and
 the Light, which passes through the Hole f, may be bent sideways.
 The Event of the Experiment is always the same.
3530. We transmit Light through two narrow Holes, that it's Direction
 may be well determin'd, and all the Rays may follow the same
 Direction. The Hole, through which the Light is let in, must, for
 this Reason, be larger than in the foregoing Experiments, that the
 3531. Light, which passes through g, may not be too weak. Those
 smaller Holes are made use of, which are in the Plates that may be
 mov'd perpendicular to the Direction of the Axis of the Prism, that
 the Holes may answer exactly to the Prism. But as the Event of
 this



112



J. Mynde sc.

this Experiment is not always the same, and *Mariotte*, who was well versed in physical Experiments, affirms, that after the second Refraction of any Ray, the Colours appear different again; something must be mention'd, and I must speak distinctly of the Cautions that are to be observ'd.

3532.

If with the Rays of any Colour, a small Quantity of Rays of different Colours be mixt, the Colour is not alter'd thereby as to Sense; because the vivid Light hinders the weak Light from being sensible; but if such Rays, which appear to the Eye homogeneous, pass through the Prism, they are separated, and the Colours then become sensible: therefore unless the Rays be homogeneous that fall upon the second Prism, the Experiment necessarily succeeds as it is described by *Mariotte*; but who does not see that nothing can be concluded from such an Experiment if the Event be the same as that which we have described above *, the necessary Cautions being * observ'd?

3533.

The Prisms that are to be made use of, especially the first, must be of pure Glass, otherwise there are Reflexions of the Rays in the Prism itself, and in the going out the heterogeneous Light is every where mixt with the homogeneous Light, which, whilst it is separated, disturbs the Experiment.

3534.

Care must be taken also, that no Light enters the Chamber, except the Ray mention'd in the Experiment; for if any such Rays be mixt with those, that make the Image, the Experiment cannot answer well.

3535.

We must also take care that the Experiment be not made when the Sky is not clear enough; for then there are many Rays among those, that proceed directly from the Sun, which follow different Directions; which chiefly happens, when there are Clouds towards the Sun, which reflect Light vivid enough.

3536.

C H A P. XXII.

That the Rays are not alter'd by any Reflexion.

WE prove by Experiments that the Rays are not altered by Reflexion.

3537.

EXPERIMENT I.

An oblong Image of the Sun being given, tinged with homogeneous Colours *, let the different Colours of it fall successively * upon the Surfaces of different Bodies, for Example, upon that of

3538.

3484. 3500.

Cloth of different Colour, or Silk, or of any other Body; or we may take any painted Bodies, or the Powders themselves, that Painters make use of; in all these Cases the Rays in Reflexion keep their own Colour; the red Rays remain red, whether they are reflected from a red Body or a blue one; but the Colour is more obscure and dark, when the Colour of the Rays does not agree with the Colour of the Body, notwithstanding it is not alter'd.

A S T A N D for the two P R I S M S.

3539. Upon the wooden Stand P two wooden Pillars are plac'd, about
 Plate 114. a Foot high, which support the transverse Piece of Wood MM.
 Fig. 1. The lower Prism A B is laid upon the smaller Pillars G G*, which
 * 3249. turns about it's Axis, and is fasten'd by a Screw at c.
 3540. The other Prism E F † is like the former; this has a Handle
 † 3249. H; *n* passes through this, which makes one End of the Axis,
 through a Hole at the End of the Handle; the other End *o*
 goes into an Incision, tending obliquely downwards; and the
 Prism is fasten'd by the Screw *m*; the Handle is supported toge-
 ther with the Prism, by Means of the Copper Plate L, which
 may be rais'd and let down, and which is retain'd by the Screw *n*.
 3541. The Handle H is join'd to the Plate L in such Manner, that the
 Prism, it's horizontal Position being kept, together with it's Han-
 dle, may be turn'd about, a vertical Line passing through *p*; and
 the Handle is fasten'd by Means of the Screw I. We shall call
 this last Motion the Conversion of the Axis of the upper Prism.

E X P E R I M E N T 2.

3542. We let Light into a dark Chamber through two Holes*, in the
 Plate 113. same Manner as through one in the first Experiment of the twen-
 Fig. 2. tieth Chapter. The lower Ray is transmitted through the lower
 * 2705. 3476. Prism, and gives an oblong Image; the upper Prism is rais'd, by
 3477. moving the Plate *l*, or let down and fasten'd at that Height, that
 another Ray may fall upon it; by Help of this we make a second
 * 3541. Image, which, by turning the Axis of the Prism*, we dispose in
 such Manner as to join the Images sideways; then, by turning one
 of the Prisms about it's Axis, we depress one Image in such Man-
 ner, that the red Colour of it may answer to the violet Colour of
 the other Image. The Paper being removed which covered the
 † 2775. wooden Rectangle †, the upper Ruler L L of the Rectangle, is to
 be

be placed in such Manner, that the said Spots, the one red R, and the other violet V, may fall upon the Middle of the Ruler. This is white in that Place, and every where else black, with the rest of the Rectangle and the Stand.

Now if a Spectator at the Distance of sixteen or twenty Feet beholds these Spots R and V, attending to that which has been shewn above*, he will see the violet Spot at *u*, and the red one less removed out of its Place at *r*; so that there is no Alteration in the Colour's Refrangibility, though the Rays are reflected. 3543. 3493.

The Parts of the Images which pass above and below the Ruler LL, must fall upon the black Plane, that they may not disturb the Experiment. 3544.

But this Experiment answers best, when there is another dark Chamber near at Hand, into which these Rays may penetrate: If then the Spectator beholds these Spots a little obliquely, none of the useless Light can be reflected to him. 3545.

EXPERIMENT 3.

This Experiment succeeds best of all also, if there be two Chambers separated only by a Door, and they be both dark; then the Prism being placed at the Distance of sixteen or twenty Feet from the Door, the Rays are separated, that an oblong Image of the Sun may be made*, which in the other Chamber falls upon the Paper at RV, at the Distance of upwards of thirty Feet from the Prism. 3546. Plate 114. Fig. 2. 3483.

Upon this Paper T are drawn black Lines parallel to one another, about the sixteenth Part of an Inch broad, which are enlightened by the said oblong Image of the Sun, according to the Length of which, the Lines are disposed; there is moreover a convex Lense of five or six Inches Diameter, such as has been used above; or if this be not so convenient, we make of one more convex, which collects the red Rays proceeding from a radiant Point six Foot distant from the Glass, at an equal Distance; if this Lense be at the Distance of six Feet from the said Image, the Parts of the Lines, which are in the red Colour, are represented upon the Paper, by Rays collected by the Lense, at the Distance of six Feet also, exactly in the red Image, but the Paper must be moved nearer about three Inches and an half, that the Parts of the Lines, illuminated with a purple Colour, may appear distinct in the Image of the said Colour: the intermediate Colours give their Images at intermediate Distances; the violet Colour is so weak, that the Lines in it cannot be represented. This 3547. 3507.

3548.

This Experiment answers also, though there be not a second dark Chamber; but then we ought to prevent the extraneous Light, which enters into the Chamber through the Hole, from making the Representation of the Lines too weak, by means of a Curtain or any other Way, if we do not make use of the Helioſtate.

3549.

Therefore this Experiment is a Confirmation also, that the Colour of the reflected Rays is not alter'd by a new Refraction through a Lenſe; as likewise that the most refrangible Rays are inflected

3550.

more than others, in paſſing through the Lenſe: This laſt Experiment likewise proves, that *the different Refrangibility of the Rays is the Reason that Telescopes are not perfect*; for the Rays proceeding from Points at an equal Diſtance, are collected at various Diſtances from the Lenſe, according to their different Colour; whence also the Representation of the Points are at unequal Diſtances from the Eye-glaſs, which therefore cannot all be ſeen perfectly through it.

3551.

With Regard to the Reflection of the Rays, that the *Rays are in general more eaſily reflected, which have a greater Refrangibility*, for the greater the Refraction of the Rays is, the leſs Obliquity is required, that they may be all reflected*.

* 3257.

PRISMS, *with their Stands, whereby Experiments concerning Reflection are demonstrated.*

3552.
Plate I 14.
Fig. 3.

In theſe Priſms A B, C D, that are equal and ſimilar, are made uſe of; the Baſes of them are rectangular Iſoſceles Triangles, ſo that when joined, the greater Surfaces being apply'd, they make a Parallelopiped, whoſe Baſes are Squares; the Baſes of theſe Triangles thus joined are put into the Boxes E E, and the Priſms are faſtened by Means of the Screws *f, f, f, f*, which preſs the Plates *g, g*: Theſe are apply'd to the Glaſs immediately, and are bent in ſuch Manner that the Screws may not damage the Glaſs, though they paſs through the Plates, whiliſt they are joined to them.

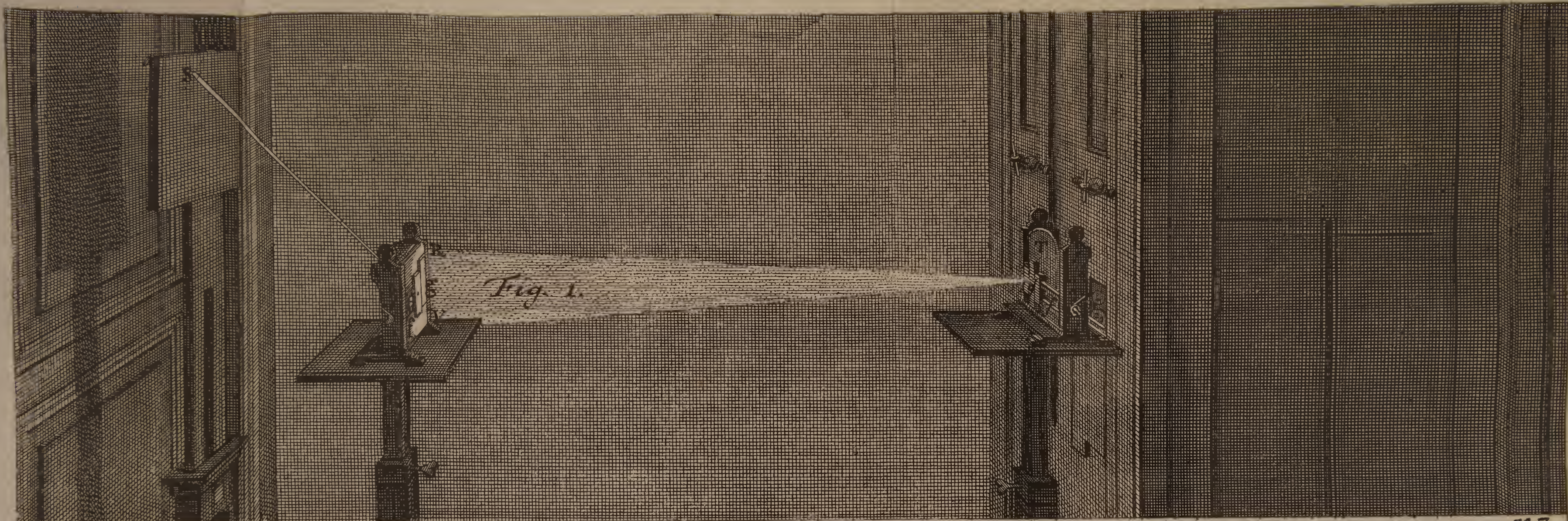
3553.
Plate I 14.
Fig. 4.

The Priſms thus joined together, may be turned about their common Axis, by Means of the Points cohering with the Boxes: To this End we put the Priſms upon the wooden Stand S, and the Priſms are kept in the required Poſition by Means of the Screw *g*.

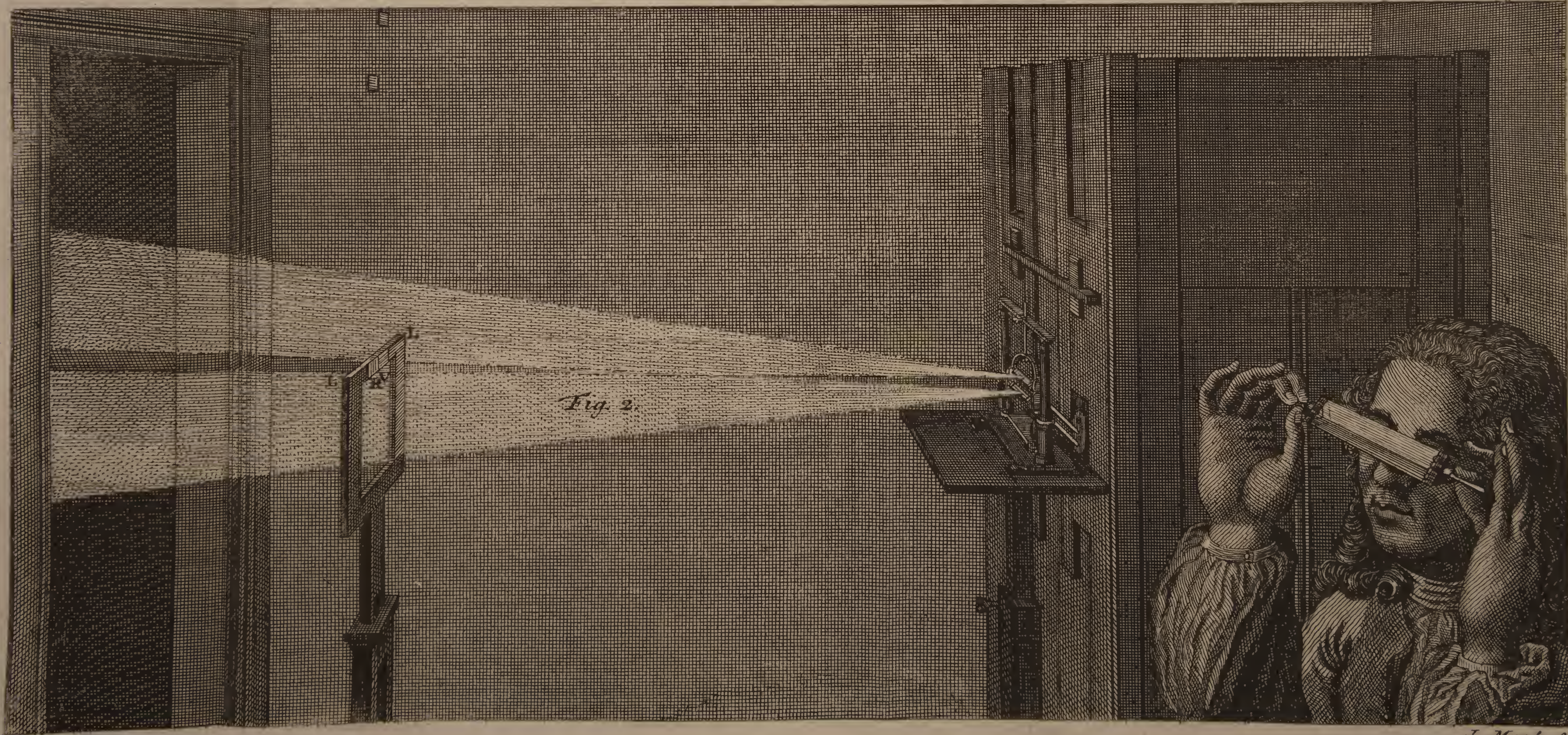
3554.

Sometimes only one Priſm is made uſe of, then the Places, which occupy the Extremities of the other in Boxes, are filled with wooden Triangles, as H (*Fig. 3.*) and the one Priſm is faſtened in the ſame Manner, as has been ſaid of the two, and is laid upon the Stand.

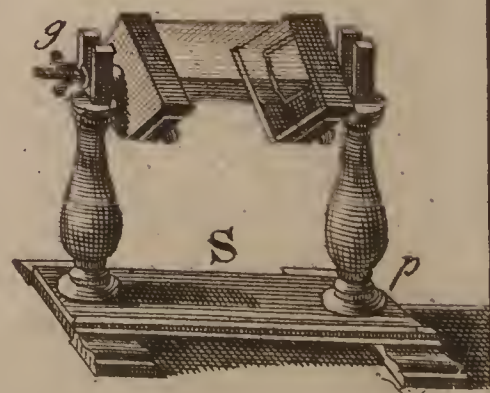
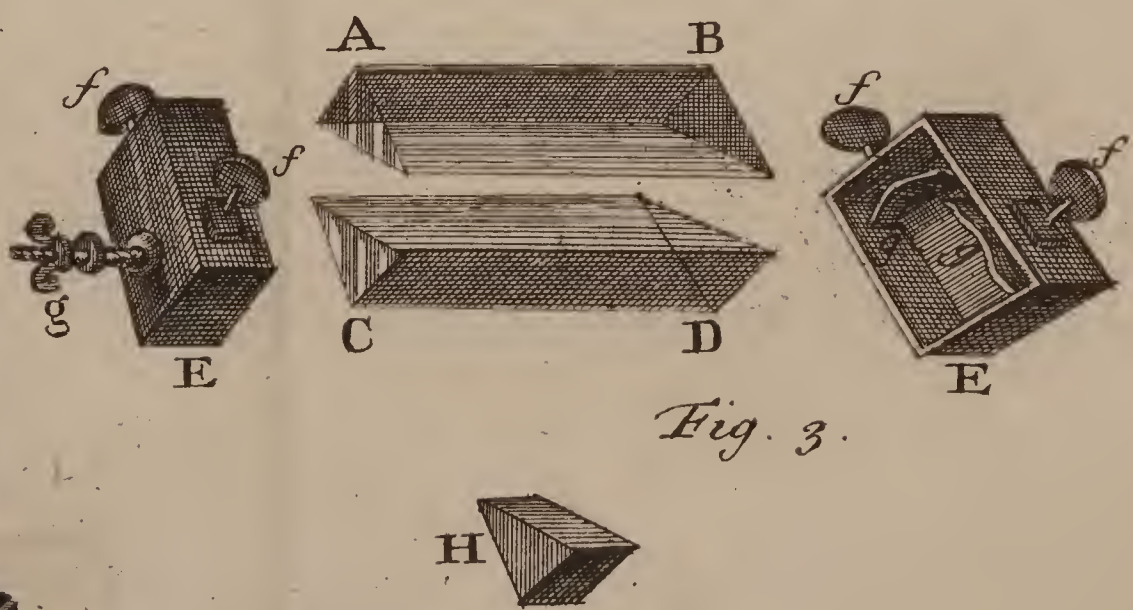
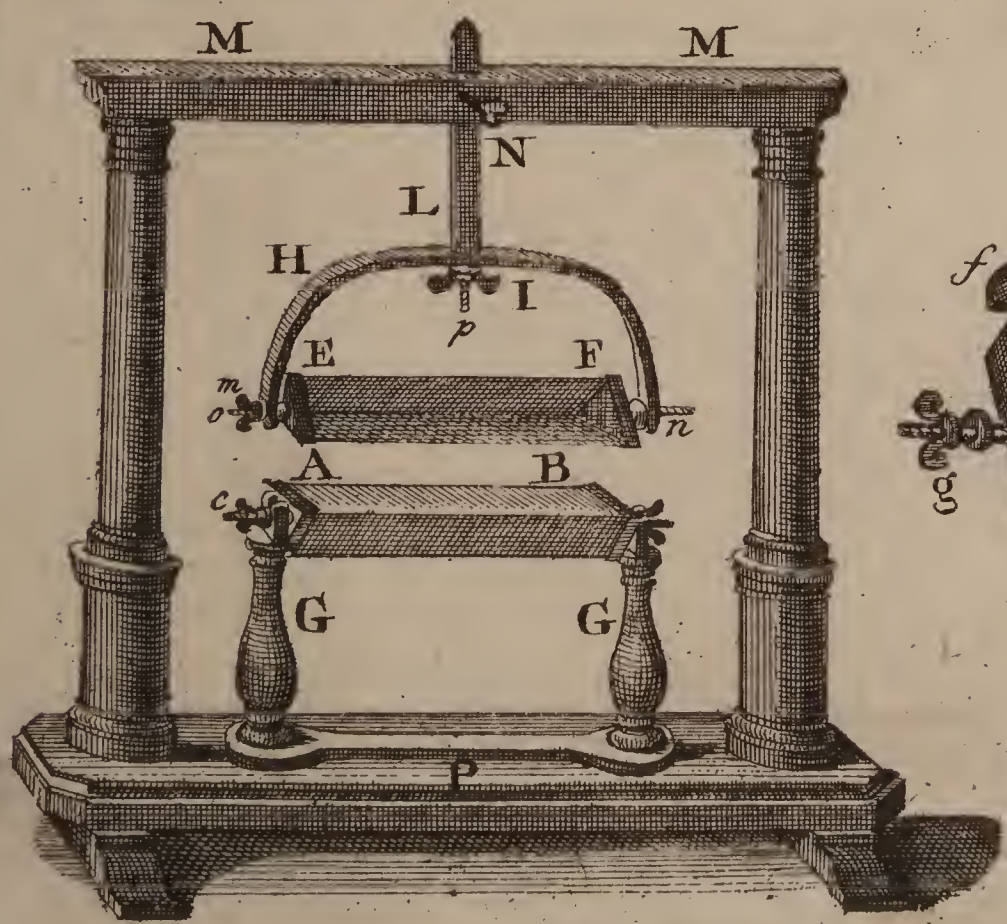
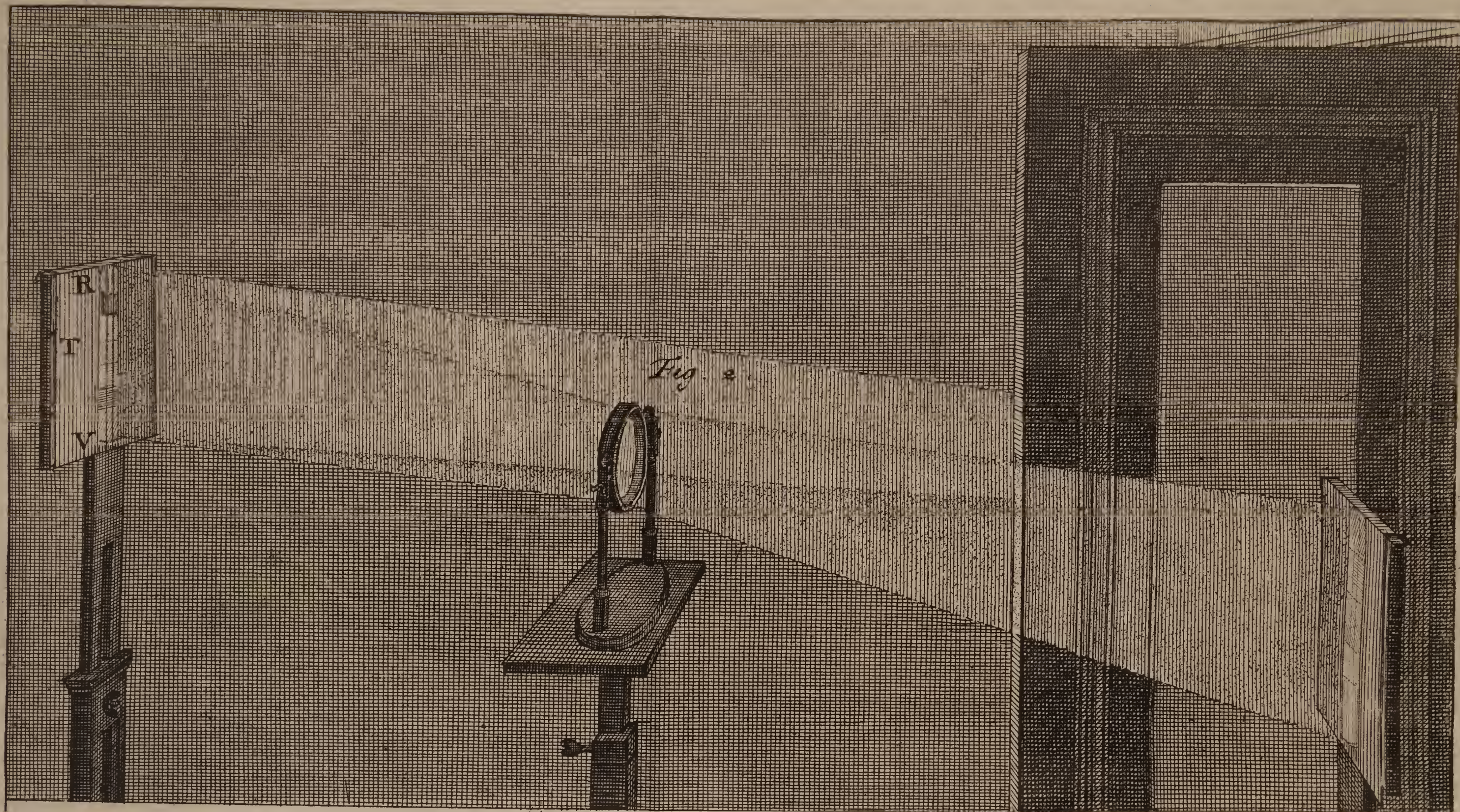
We



113



J. Mynde sc.



We represent the Prisms in an horizontal Position, we may also make use of them in a vertical Position, for the Length of the Point must be determined in such Manner, that the Side op , and the End of the Point, may be in the same Plane perpendicular to the Axis of the Prism.

3555.

EXPERIMENT 4.

A Ray of the Sun is let into a dark Chamber, through a Hole, whose Diameter is equal to a Quarter of an Inch.

If the Direction of it be not convenient enough, it must be reflected by a Mirror, and indeed brought into an horizontal Direction; this at least is most convenient, and then the Prism is to be put into a vertical Position.

3556.
Plate 117,
Fig. 1.

Only one Prism AB is made use of, into which the Rays penetrate, through one of the smaller Sides of it, in such Manner, that it is partly reflected by the greater Sides, and Part of it goes out.

This last Light falling upon the white Paper t , gives a colour'd Image, the Prism is turned in such Manner, that the Rays may pass through near the Surface of the Prism; the reflected Light is refracted by the Prism P , and gives a colour'd Image RV at T .

Now if you continue to turn the Prism slowly, in such Manner, that the Obliquity of the Rays falling upon the lower Side be increased, the violet Rays will not be able to penetrate into the Air, but they will all be reflected: If you continue the Motion all the purple Rays are reflected, afterwards the Blue, and the rest according to their Order in the Image r, v , which continually ascends, whilst the upper Part vanisheth, the red Part, which consists of the least refrangible Rays, vanishes last.

3557.

In the mean Time the Colours of the Images RV are altered, and that becomes more intense successively, which vanishes in the other Image.

3558.

C H A P. XXIII.

Of the Mixture of Colours, and Whiteness.

WE have already said that the Refrangibility and Colour of Rays is not changed by the Mixture of Rays of different Refrangibility *, which is manifest by Experiments.

3559.

* 3413.
Ex-

EXPERIMENT 1.

3560. This Experiment is made in the same Manner as the second of
 * 3541. the foregoing Chapter, but by turning the Axis of the upper Prism*, the Spots are confused, and make one purple Spot; but the Colours appear separate to a Spectator, who beholds it through a Prism, and neither the Colour nor Refrangibility are altered by this Confusion of Colours.

EXPERIMENT 2.

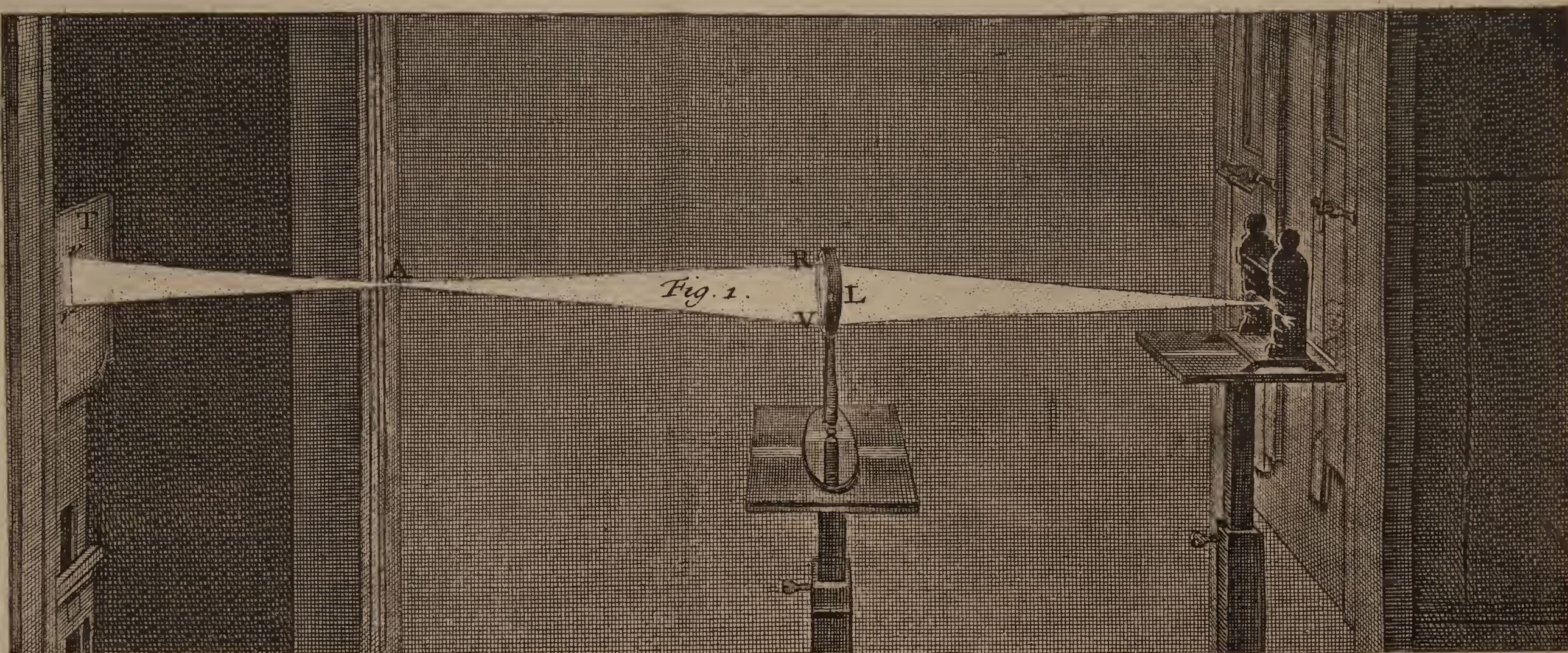
3561. If the oblong coloured Image of the Sun, which was spoken
 Plate 115. of in the first Experiment of the twenty first Chapter, falls upon the
 Fig. 1. convex Lense L * at R V, placed at the Distance of six Feet from
 * 3547. the Prism BB; the diverging Rays converge by the Refraction of the Lense, and mutually intersect one another at A, at the Distance of six Feet; if the Frame T be at a greater Distance, the Rays, which diverge again after their Intersection, come to it dispersed, and there is again given an oblong colour'd Image; but the Colours, by Reason of their Intersection at A, are disposed in a contrary Order, but they are not altered by the Mixture at A.

EXPERIMENT 3.

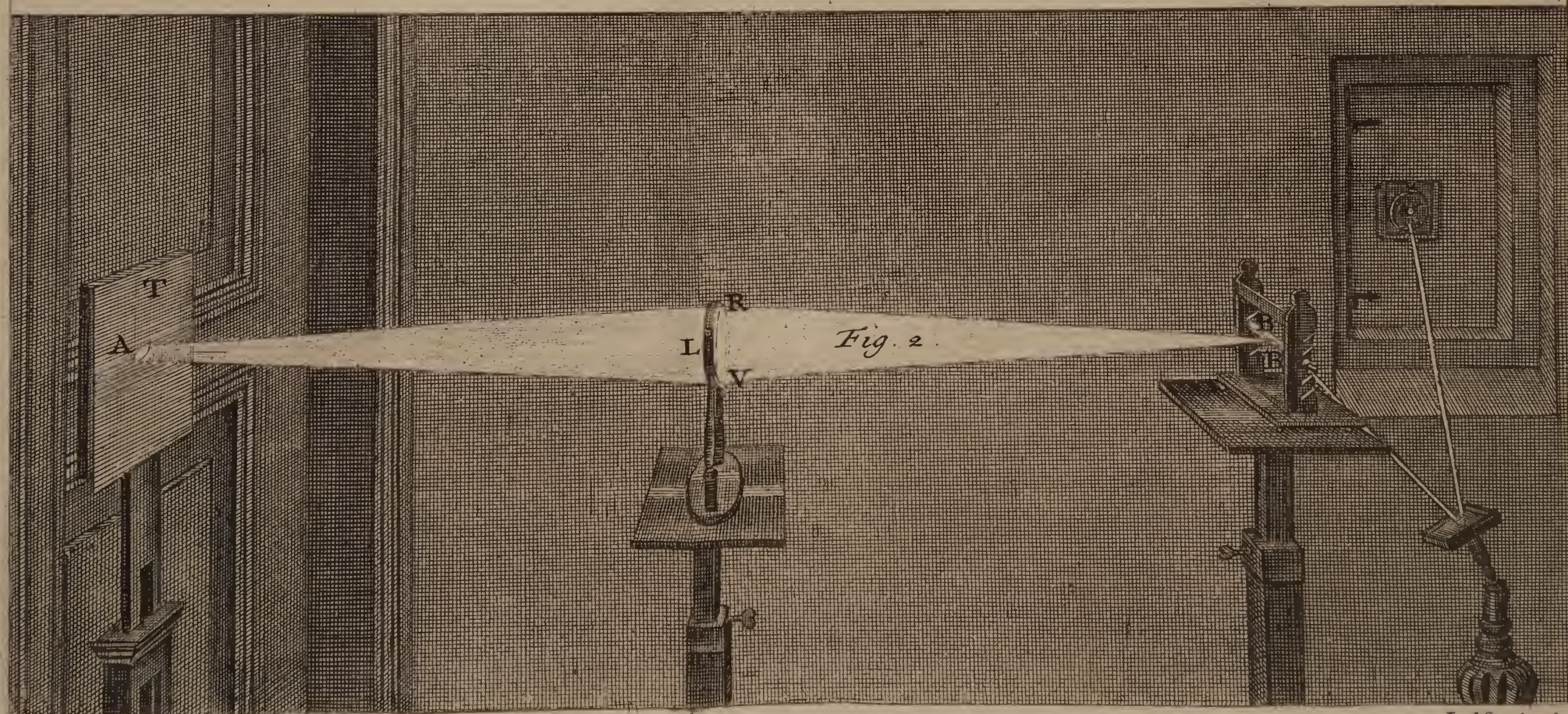
3562. All Things remaining as in the foregoing Experiment; if some
 Plate 115. Rays of the Image R V be intercepted by the black Paper, which
 Fig. 1. alters the Mixture, which by this Method may be varied at Pleasure, the Colours of the rest of the Rays, which are again separated, are not altered. *If the Sun Rays, as they come to us, be wholly reflected by any Body, this appears white*; but these Rays are
 3563. an Assemblage of Rays of different Colours †; whence we infer
 * 3465. 3495. that a Mixture of different Colours constitutes Whiteness, for if the
 3564. Colours which are observed in the oblong Image of the Sun, so often mentioned, be mixed and confused, in the same Proportion as they are in that Image, Whiteness is produced; which also proves, that in that Respect the Rays are unchangeable. The Rays that come from the Sun appear white, but if they are separated, their Colours are discovered; and, if they be mixed again, the Whiteness will be restored.

EXPERIMENT 4.

3565. Things being disposed as in the two foregoing Experiments,
 Plate 115. let the Board T be placed at A, in the very Place where all the
 Fig. 2. Rays



115



J. Mynde sc.

Rays of the Image R V are mixed together; there will be a Whiteness at A, if with a black Paper you intercept the red Colour of the Image R V, the white will vanish, and the Colour at A be bluish; but if you intercept the violet and blue Rays, the white becomes reddish.

If we would have the white Spot greater, we make use of that Lense which has been mentioned in the fifth Experiment of the twentieth Chapter, but we place this in the Middle between the Prism and the Board T, which is at the Distance of sixteen Feet from it.

3566.

EXPERIMENT 5.

Take three triangular Prisms made of glass Plates *, B B, C C, D D, containing Water; the Sun Rays are refracted through the Prism B B, as in the third Experiment of the twentieth Chapter, and the oblong Image of the Sun falls upon the Face of the Prism C C, placed in a Situation parallel to the Face of the Prism B B, at the Distance of three or four Feet, out of which the Rays go. In the second Prism the Rays undergo Refraction, contrary to that which they did in the first, by Reason of the Parallelism mentioned, and because the Angle which the glass Planes make, through which the Rays pass, are equal: Therefore the first Refraction is destroy'd by the second, and the Rays go out of the Prism C C at R V parallel, for the Prisms are so placed, that if the Prism C C be brought near the other, and the parallel Faces mutually touch one another, the Light may pass through the Medium, terminated by parallel Planes; for both the Prisms joined together make a Parallelopiped, through which Light, of any Refrangibility passes without Change of Direction * * now the Prisms are separated, that the heterogeneous Rays may be separated, before they again become parallel, if these coloured Rays fall upon the third Prism D D, and in passing through it undergo a Refraction like that which they have undergone in passing through the first or second Prism; the Rays that go out at r v converge, on Account of unequal Refractions in Rays of different Colours, and concur at A, in which Place also Whiteness will be produced, as in the foregoing Experiment.

3567.

Plate 116.

Fig. 1.

* 3491.

2792.

EXPERIMENT 6.

Let R V be an oblong coloured Image of the Sun, as in the first Experiment of the twentieth Chapter, and let there be a Spectator at S at a Distance from the Plane T, as much as the Prism is distant from it, by which the Rays are separated; if he looks at the

3568.

Plate 116.

Fig. 1.

Image $V R$ through another Prism like the first, as was said of the Hole in the fourth Experiment of the same Chapter, he will see the Image round and white; the second Refraction destroying the first in such Manner, that the Rays enter the Eye being again mix'd.

EXPERIMENT 7.

3569.
Plate 118.
Fig. 1.

All Things being ordered as in the fourth Experiment foregoing, the Prism is placed at A in the Point in which the Rays being mixed are white; the Rays are refracted downwards, and indeed in such Manner, that the Deflection is the smallest; which Position of the Prism is found, by turning it about its Axis, then (for we suppose the Prism P and A to be similar) the second Refraction destroys the first, and the Rays go out of the second Prism along e, f , as they enter into the first along c, d , parallel and white; now if this white Ray ef be refracted through the third Prism B horizontally, we have a new oblong Image vr , tinged with the Colours often mentioned.

EXPERIMENT 8.

3570.
Plate 117.
Fig. 2.
* 3552.

In this Experiment all Things are disposed, as in the last Experiment of the foregoing Chapter; but a second Prism CD^* is joined with the Prism AB , a small Piece of Paper being put between, at the Extremities of the Prisms.

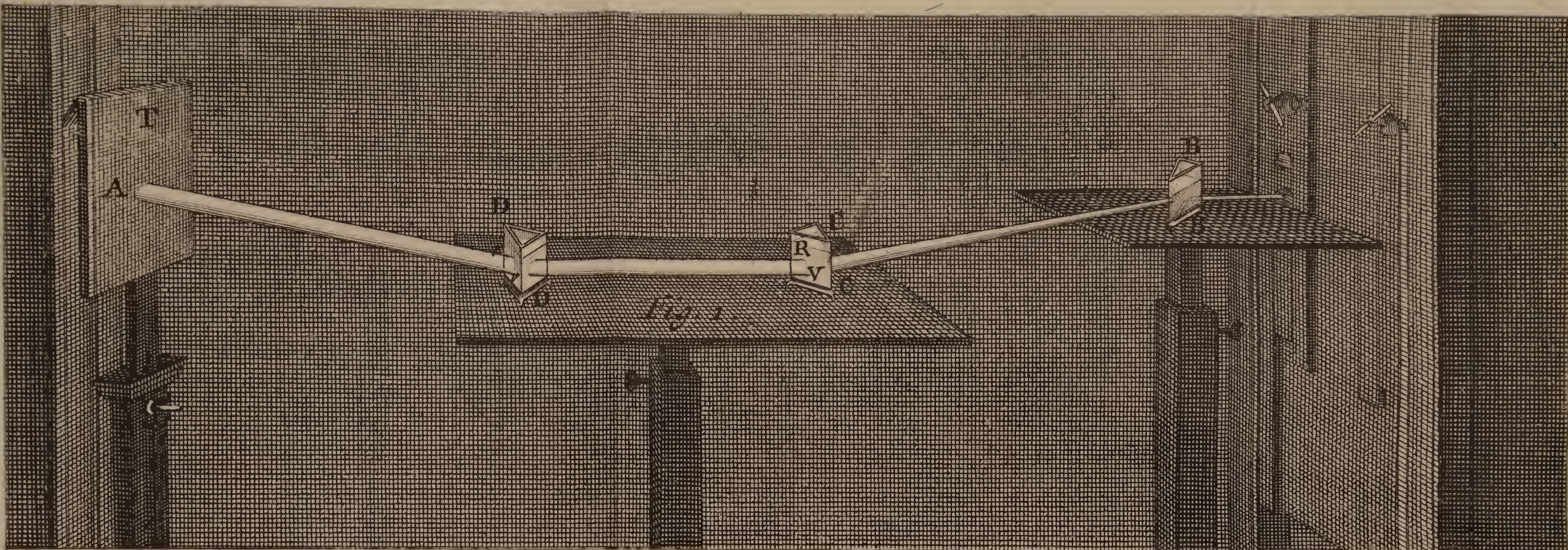
Then the Rays, which pass through the two Prisms, make a white Spot m , such as the Rays reflected at M give.

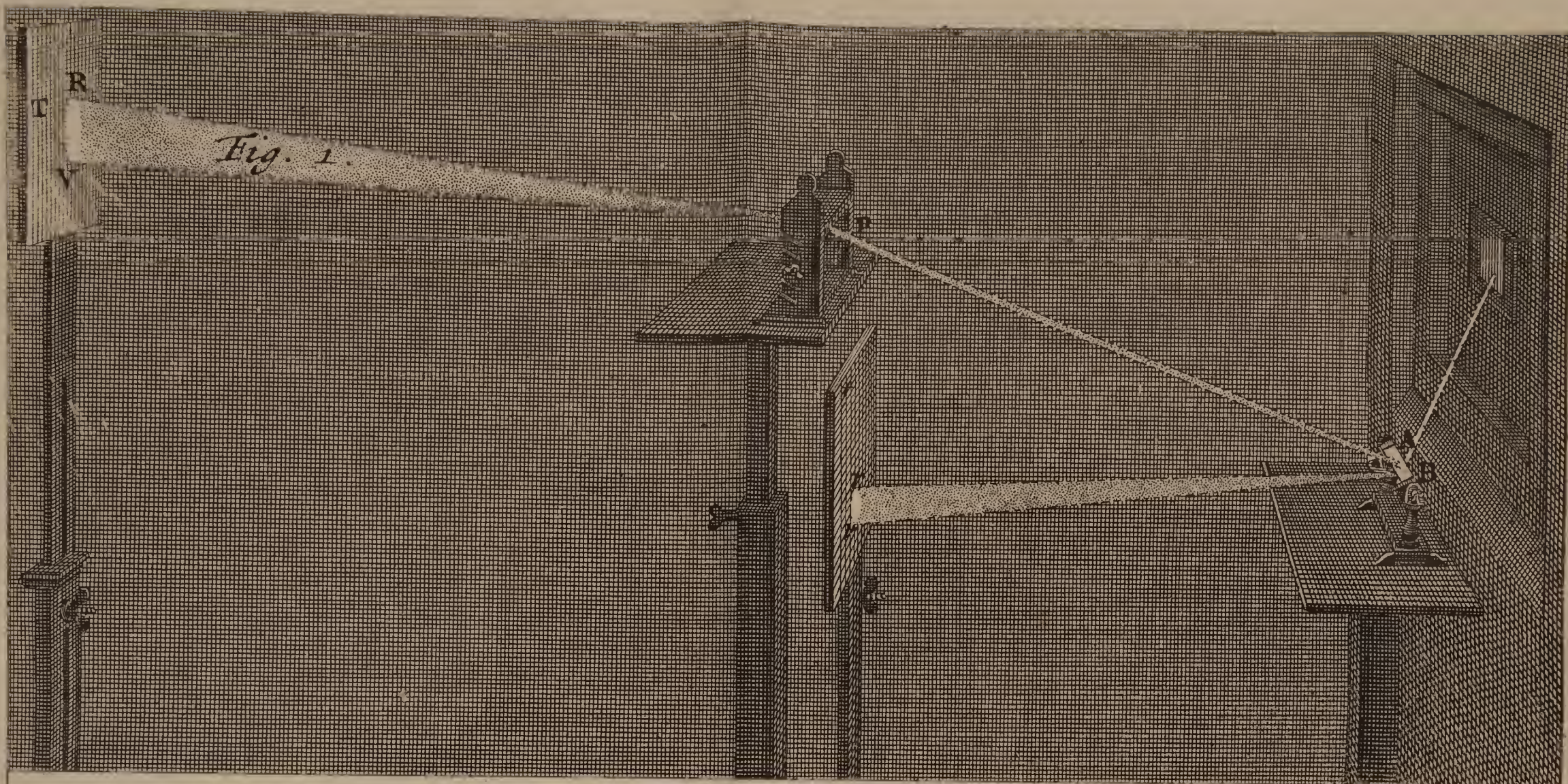
Now the Prisms being turn'd about their common Axis, in such Manner that the Rays of all the Colours may be successively reflected, the Whiteness of both the Spots M and m is alter'd, by Reason of the Alteration of the Mixture of the Rays.

3571. If the Planes T, t , being removed, the Prisms be placed at Mm , by which the Colours are separated, we shall have the same Phenomena in the colour'd Images, that were mention'd before*.

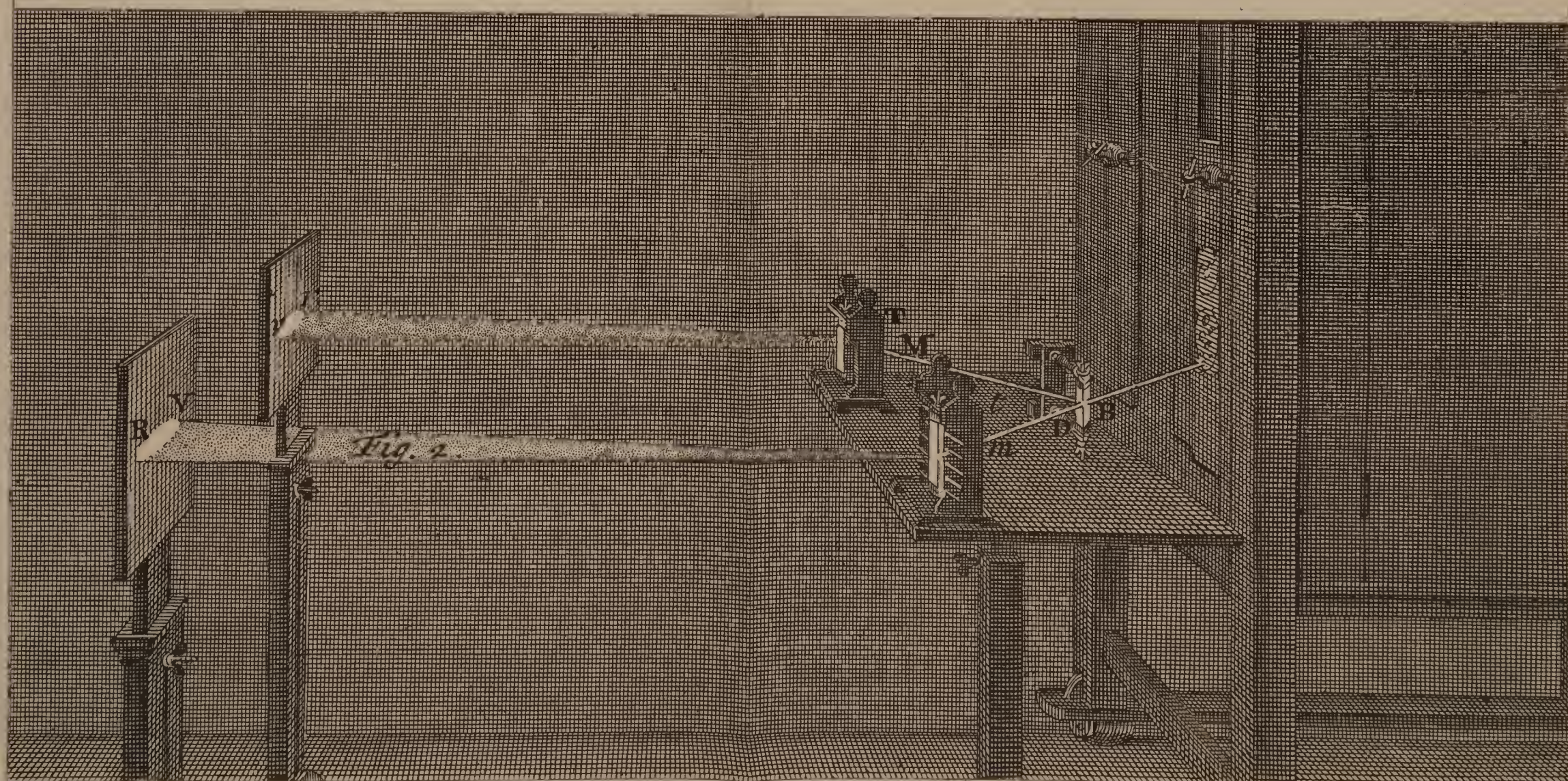
3572. *A Mixture of all the Colours, which are observed in the oblong Image of the Sun, is not necessary to constitute Whiteness; the Whiteness of the Sun's Rays is a little inclined to yellow; and the yellow Rays being partly taken out of the Mixture, the white becomes more perfect. Whiteness is produced from the Mixture of four or five Colours, the just Proportion being kept; the primary Colours, that is the homogeneous Colours, being mix'd, generate many Colours different from the homogeneous, or primary Colours; oftentimes a Colour,*

3573.





117



J. Munro sc.

Chap. 24. of Natural Philosophy.

259

a Colour, like an homogeneous Colour, is made up of the Mixture of other Colours, and these three Colours, red, yellow, blue, being given, we may imitate all the Rest; but we ought not from thence to infer, that there are only three primary Colours, since we really discover seven: Nevertheless *when no Difference is observed between the homogeneous Colour, and that which is mixed by the naked Eyes, this is sensible through the Prism.*

3574.

EXPERIMENT 9.

Let any small Objects, as Letters on Paper, Flies, and other such like Objects, be observed through a Prism, if they be exposed to the mix'd Light they appear to be confused; if they be enlightened with homogeneous Light*, when seen through the * Prism, they are terminated by distinct Limits.

3575.

3510.

C H A P. XXIV.

Of the Rainbow.

HA V I N G finished what relates to the Rays enlightening Bodies, we must not leave this Subject, without explaining a Phenomenon, which is too remarkable and common to be passed by in Silence.

3476.

The Rainbow, or Iris, is what every Body has often seen: Having first premised some Things, we must explain what is the Cause thereof.

Let there be Water encompassed with Air, terminated by the Circle BDFH, let homogeneous Rays, which are parallel, fall upon it, whereof AB is one; let the Semi-diameter CB be drawn and continued to N, this is perpendicular to the Surface separating the Mediums, therefore ABN is the Angle of Incidence; this Angle* is equal to the opposite vertical Angle CBL*, whose Sine is CL* perpendicular to BL, and going through the Center, the Ray is refracted towards the perpendicular*, and CBM is the Angle of Refraction, whose Sine is CM drawn from C perpendicular to BD; for every Ray, such as AB, the Ratio between the Lines, such as CL and CM is the same*.

3577.

Plate 118.

Fig. 2.

2918.

15.El.1.

2798.

* 2809.

The Ray BD in Part penetrates into the Air in the Direction E, and in Part is reflected in the Direction DF, so that the Angle of Reflection CDF, is equal to the Angle of Incidence BDC*;

* 3241.

consequently BD and DF are equal; also the Ray DF does in Part go out of the Water along FG , and is reflected along FH ; which in the same Manner does in Part go through HI , and in Part is reflected; but we do not consider this Reflection, and other farther Reflections and Refractions; they are too weak, because of the several Divisions the Light has undergone.

EXPERIMENT I.

3578.
Plate 119.
Fig. 1.
|| 2794. 2795.
2769.

We let an horizontal Ray into a dark Place *, and intercept it by the Board, whose Incision is horizontal $\parallel$, and which we represent by the Line AB . In the Incision we leave a small Aperture, in such Manner, that only a small Ray may pass through; the Cylinder V made up of pure Glass that is thin contains Water, into which the Ray ABC passes obliquely, and is refracted along CD ; it is reflected along DE , and goes out along DF ; it is further reflected along EG , and so on: We seek the Position of the Glass by Trial and the Breadth of the Ray, that the Experiment may be very sensible, in which Case the Reflections are so repeated, that they extend themselves beyond I ; but the sixth Ray is scarce visible, and often cannot be perceived.

Plate 118. Fig. 2. The Ray FG , which after one Reflection goes out of the Water, makes the Angle GPA with the incident Ray AB , which varies in different incident Rays; therefore, though these Rays should be parallel, *they will be dispersed when they go out after one Reflection*, as is evident by looking at the Figure.

Plate 118. Fig. 3. 3579. The Ray EE , which being continued, passes through the Center C , is not turned out of its Way, either by Reflection or Refraction.

* 3272. 2793.

As you recede from this Ray, the Ray which returns is less and less inclined continually to the incident Ray. Thus the Ray DD , which goes out of the Water along dd ; and returns along that Line, makes a greater Angle with DD , than the intermediate Rays DD and EE do make with their returning Rays, which go out of the denser Medium.

3580. Let BB be a Ray, in Respect of which this Inclination is the least of all, that is, which makes an Angle as APG (Fig. 2.) the greatest of all: Beyond BB , the returning Rays are more inclined towards the incident Rays; thus AA returns along aa :

3581. From this Dispersion of the returning Rays, receding from the Place where the Rays are bent, they become continually weaker and weaker; and their Colour cannot be perceived throughout the whole

whole Space which they fill, though the Colour of the incident Rays be vivid; the Colour in the returning Rays is only sensible where the adjacent Rays are parallel, and those next to them diverge but a little, so that at a great Distance they are dense enough to be perceived: These only are said to be efficacious, and will be so, where the incident Rays being refracted, meet in the very Point of Refraction.

Let A B, *a b* be adjacent Rays, parallel to one another, and falling upon a circular Surface terminating the Water; if these, being refracted along B D, *b D* meet in D the Point of Reflection, the reflected Rays D F, *F f*, will make with *F f* Angles equal to those which D B, *D b* make with B *b*; and so the refracted Rays, F G, *f g*, will be parallel * and efficacious †. In the first Scholium following we have demonstrated how, in this Case, when the Ratio between the Sines of Incidence and Refraction is given, the Angle formed by the incident Ray and the returning efficacious one, may be determined, that is, the Angle A P G, which here is the greatest of all.

3582.

Plate 118.

Fig. 4.

* 3790.

† 3581.

When the Ratio between the Sines of the Angles of Incidence and Refraction varies, the Angle A P G is changed; which therefore is different, according to the different Refrangibility of the Rays.

3583.

If the Surface abovementioned be enlightened by heterogeneous Rays, as they flow from the Sun, the efficacious Rays of different Colours do not make equal Angles with the incident Rays, and so the Colours are separated by Help of this Refraction.

3584.

EXPERIMENT 2.

This Experiment is made in the same Manner as the foregoing one, but we make use of another Board T*, because it is not necessary, that the Ray be so straitened; and the Height of the Ray, going into the Water, may now be determined at Pleasure. The Position of the Glass is also easily discovered by making Trial, that the efficacious Rays of all Colours may return; the Rays that pass through the Slit of the said Board are sufficient that we may have all the Colours.

3585.

Plate 119.

Fig. 2.

* 2768.

If these efficacious Rays fall upon the white Paper, at the Distance of four or five Feet, the Colours will appear separated according to their Order of Refrangibility*, and by Reason of the Figure of the Glass the Colours will appear vertical.

* 3501.

3586.

If the Paper being removed the efficacious Rays enter into the Eye of a Spectator S, placed at a greater Distance, that the Colours may be more separated, the Spectator will see that Colour, the Rays of which enter into the Eye; and he will perceive all the Colours successively, by moving his Eye.

3587.

Plate 119.

Fig. 3.

But with Regard to those Rays, which after a double Reflection in Water emerge, they will be efficacious, if they be parallel after the first Reflection; for then FH , fb , are in the same Manner inclined to Hb , as BD , bd to Bb ; and therefore, supposing the incident Rays AB , ab to be parallel, the emerging Rays HI , bi will be parallel too, that is, efficacious*.

* 3249.

3588.

Also in the second Scholium following, we demonstrate, how in that Case the Angle HPB , formed by the emerging and incident Ray is determined, which Angle in that Case is the smallest of all similar ones, being different according to the different Refrangibility of the Rays: Whence also in that Case, *the efficacious Rays of different Colours, supposing the incident Rays parallel, are separated after a double Reflection.*

3589.

EXPERIMENT 3.

3590.

Pl. 119.

Fig. 2.

All Things being ordered as in the last Experiment, the Situation of the Glass that contains the Water is altered, so that the Rays which are efficacious after two Reflections in the Glass fall upon the Paper, or, when this is remov'd, upon the Eye.

3591.

What has been hitherto explained, may be applied to the *Rainbow*; in order to produce which Phenomenon, *it is required that Drops of Water be suspended in the Air; that the Spectator be placed with his Back towards the Sun, between it and the Drops, and that there be a dark Cloud behind the Drops*, that the Colours may be more sensible, for these are scarcely perceived, if vivid Light enters the Eye at the same Time.

3592.

These Things being supposed, if we conceive all the Drops to be cut by Planes, passing through the Centers of the Drops, and the Sun, and the Eye of the Spectator: What has been demonstrated* above, may be applied to each of these Sections.

* 3581. 3582.

3583. 3584.

3587. 3588.

3589.

3593.

Plate 118.

Fig. 4.

Here we speak of Rays which go out of Air into Water. In red Rays, that is, such as are the least refrangible, the Ratio between the Sine of the Angle of Incidence and the Angle of Refraction, is as 108 to 81, or, which is the same, as 4 to 3; with which Numbers, if the Computation be made, the Angle APG will be 42 Degrees 2', but if we speak of violet Rays, the Ratio

the Sines is as 109 to 81; which Numbers give the same Angle A P G of 40 Deg. 17 Min.

If the Computation be made for the Angle A P I, and the Rays be red, the Angle will be 50 Deg. and 57 Min. if the Rays be Pl. 119. violet, the same Angle is 54 Deg. 7 Min. as will be seen in the Fig. 3. Scholiums.

Now let the Drops be supposed to be dispersed through the Air, and enlightened by the Sun's Rays, which are parallel to one another, and to the Line O F, passing through the Eye of the Spectator; let us conceive the Lines e O, E O, B O, b O, and let the Angles e O F be 40 Deg. 17 Min. E O F 42 Deg. 2 Min. B O F 50 Deg. 57 Min. b O F 54 Deg. 7 Min. the same Lines form Angles with the incident Rays de , D E, A B, ab , respectively equal to the Angles aforementioned; therefore, if the Drops be conceived at e , E, B, b , the efficacious violet Rays will enter the Eye, after one Reflection in the Drop e ; and the red efficacious Rays come to the Eye from the Drop E; also after one Reflection the other intermediate Colours are observed between e and E, in the Order beforementioned*. After two Reflections in the Drop, the efficacious red Rays come to the Eye from the Drop B, and the violet efficacious ones from the Drop b ; between these Drops the intermediate Colours appear in the same Manner as between E and e , but they are disposed in a contrary Order, and, by Reason of their double Reflection, are also weaker. 3595. Pl. 120. Fig. 1. * 3501. 3596.

Let us conceive a Line, as O e , to revolve about a fixed Line O F, keeping the Angle e O F, and to form a Cone or Part of a conical Surface; in every Situation the Line e O makes an Angle of 42 Deg. 17 Min. with the Sun's Rays, which are parallel to one another, and to the Line O F; if therefore the Drops be diffused near Part of the Surface of this Cone, at the same or different Distances the Eye will see the violet Bow: The same may be said of the other Colours; therefore, when the Drops are suspended in the Air, a Spectator sees a Bow, having the Breadth e E tinged with homogeneous Colours aforementioned*, that are disposed in the same Order, as in the Experiments with the Prisms; because the heterogeneous Rays are separated as much in the Drops as in the Prism*. 3597. 3598. * 3501. * 2472. 3584.

By the same Way of Reasoning it is evident there will be a broader Bow encompassing the first, in which the same Colours will appear in a contrary Order and weaker. 3599.

EXPERIMENT 4.

3600. Hanging up a Piece of black Cloth, exposed to the Sun Rays, let there be between this and the Sun, a Spectator beholding the Cloth, and let Water be dispersed between the Cloth and the Spectator, that it may be resolved into small Drops, the Spectator will see the Rainbow, at least the inner one.

SCHOLIUM I.

Computations concerning the first Rainbow.

3601.
Plate 118.
Fig. 1.

SUPPOSING what was explained in N. 3582, we must demonstrate, how the Angle APG is determined, which the incident Rays make with the efficacious returning Rays, the Ratio between the Sines of Incidence and Refraction being given. Let this Ratio be the same as is given between I and R ; therefore, drawing Cm perpendicular to bD , and the Arch mn with the Center C , and Semi-diameter Cm .

3602. $I, R :: CL, CM :: Cl, Cm :: CL - Cl = Ll, CM - Cm = Mn.$

3603. Draw Bo perpendicular to BL ; as also Bp to BM ; and let bp be given, which makes a right Angle with Bp ; lastly, let the Points B, C , and M, m be joined by Lines.

The Triangles Bbo , BCl , are equiangular, for they are right-angled, and the Angles oBb and CBL , the Difference of each of which from a right Angle is oBC , are equal.

* 4 El. 6. In the same Manner may be proved that the Triangles BMc and Bbp are equiangular, and therefore similar*; the Triangle Mmn right-angled at n , is also similar to this; for the Sides Mn , Bp , perpendicular to the Line BD , are parallel; as also Mm and Bb , because the Lines BD , bD , are bisected into equal Parts at M and m *; therefore also Bb is double of Mm , and Bp double of Mn . Hence we deduce,

$$BL, BC :: Bo, Bb.$$

$$BC, BM :: Bb, Bp.$$

therefore by Equality

3604. $BL, BM :: Bo = Ll, Bp = 2Mn :: I, 2R :: CL, 2CM,$

* 3602. by comparing these Proportions with that beforementioned*.

3605. As the Squares of proportional Quantities are proportional*, we have

* 22 El. 6. by Alternation,

$$BL^2, CL^2 :: BM^2, 4CM^2.$$

when we deduce by Conversion and Inversion,

* 45 El. 1. $BL^2 + CL^2 = BC^2$ *, $BL^2 :: BM^2 + 4CM^2 = BC^2 + 3CM^2$, $BM^2 = BC^2 - 3CM^2 = BL^2 + LC^2 - CM^2$.

By subtracting the first and second Term from the third and fourth, whereby the Proportion is not altered, we have

BC

$$BC^2, BL^2 :: 3CM^2, LC^2 - CM^2 :: 3R^2, I^2 - R^2;$$

3606.

for there is the same Ratio between CM and LC as between R and I*. * 3602.

But as the Ratio between R and I is given, the Ratio between the Semi-diameter BC, and the Line BL is known, which is the Sine of the Angle BCL, which Angle therefore is given; therefore the Arch BN is known, as also FH, for these are equal.

As to red Rays, I is to R, as 4 to 3. Therefore,

3607.

$$27, 7 :: BC^2 (\overline{100,000^2}) BL^2.$$

And we find $BL = 50916$; which Number is the Sine of the Angle $30^\circ. 37'$. Wherefore the Arches BN and FH are each equal to $61^\circ. 14'$.

The Sine BL being given, the Sine BM of the Angle BCM is also 3608.

given; because $I (4) : R (6) :: BL (50916,) : BM = 76374 =$ the Sine of the Angle $49^\circ. 48'$. therefore the Arch BD is determined, to which * 3604.

DF is equal, and each is $99^\circ. 36'$.

TCDP being drawn, the Arch BT is $80^\circ. 24'$. and DN is $38^\circ. 22'$. 3609.

the Measure of the Angle BDT is half of the Arch BT*, also the * 20. El. 3.

the Measure of the Angle NBD is half of the Arch ND; the Angle TPB is equal to the Difference of the said Angles*, and has for its * 32. El. 1.

Measure the half of the Difference between the Arches BT and DN, and this whole Difference of $80^\circ. 24' - 38^\circ. 22' = 42^\circ. 2'$. is the Measure of the whole Angle APG, as has been said above*. * 3593.

When the Ratio between I and R varies, the Angle APG is alter'd; which is different according to the different Refrangibility, as has been said above*. * 3583.

For the violet Rays I is to R, as 109 to 81; and if the Computation 3610.

be made with these Numbers, the Arch BN is found to be $62^\circ. 39'$.

and BD $101^\circ. 11'$. as also DN $38^\circ. 32'$; lastly, BT, $78^\circ. 49'$. Therefore the

Measure of the Angle APG, which is equal to the Difference between

BT and DN, is $40^\circ. 17'$. as has been also observed above†. † 3593.

SCHOLIUM II.

Computations concerning the second Rainbow.

WE have seen that the Rays are efficacious, that return after two 3611.

Reflections in the Drop, if after the first they be parallel, as Plate 119.

DF, df^* ; in this Case dD is the half of the Difference between the Fig. 3.

Arches DF and df , or DB and db ; but their Difference is Bb minus * 3587.

Dd ; if therefore this be subtracted from that, there will remain the

double of the Arch Dl , the triple of which is therefore Bb .

The Rectangle made of DE and EB is equal to the Rectangle made

of dE and Eb^* ; * 35. El. 3.

Therefore $DE, Ed :: bE, EB$ †, † 16. El. 6.

and Bb being put so small, that it may be taken for a right Line, the

Triangles BbE , and DdE will be similar*. * 6 El. 6.

3612.

Therefore D E is to E *b*, or E B : : D *d*, B *b*, that is, as 1 to 3.

Therefore M D is divided into two equal Parts at E; and M E s a third Part of E B, and *m* E a third Part of E *b*.

3613.

Now if, as in Fig. 4. Pl. 118. the Triangles B *o b*, B *p b* and M *m n* be formed, M *m* will be a third Part of B *b*, and B *p* triple of M *n*; now if, mutatis mutandis, we apply to this Figure, what has been demonstrated concerning the said Figure*, we have,

* 3601.

$$I, R : : C L, C M : : L l, M n^*.$$

* 3602.

3614.

$$B L, B M : : L l, B p = 3 M n : : I, 3 R : : C L, 3 C M^*.$$

* 3604.

Whence by Reasoning we deduce, as above*,

* 3605.

$$B C^q, B L^q : : 8 R^q, I^q - R^q.$$

3615.

* 3609.

From which Proportion, as was said of Fig. 4. pl. 118*, the Arch B N is discovered, to which H G is equal; and because in this Case, as has been seen,

† 3614.

$$B L, B M : : I, 3 R^†.$$

The Arch B D is also discovered, to which, by reason that the Angles of Reflection are equal to the Angles of Incidence*, D F and F H are equal.

* 3271.

3616.

* 3609.

From which being given, the Arches N D T, and B *t* are easily found, the Difference of which, as follows from what is demonstrated above*, is the Measure of the Angle H P B, made by the Ray going out with the incident Ray; which Angle in this Case is the smallest of all similar ones, and different according to the different Refrangibility of the Rays.

3617.

* 3607.

Let, as above, * I be to R, as 4 to 3, and we have $72.7 : : B C_q, B L_q$, whence we find B L to be the Sine of the Arch $18^\circ. 10' \frac{1}{2}$, and the Arch B N to be $36^\circ. 21'$.

We also have, $4, 9 : : B L, B M$, and we find this last Line to be the Sine of the Arch $44^\circ. 33'$. which if it be tripled, there will be given the Arch B D T $133^\circ. 39'$. subtracting the Arch B N, there remains N T, $97^\circ. 18'$. subtracting B D T from the two right ones, there is given B *t*, $46^\circ. 21'$. and the Measure of the Angle sought A P I = G P N is $97^\circ. 18' - 46^\circ. 21' = 50^\circ. 57'$. as above*.

* 3594.

3618.

These Things relate to red Rays; as to the violet ones, I is to R, as 109 to 81. If the Computation be made with these Numbers, B N is $37^\circ. 8'$. B D T $135^\circ. 37'$. N T, $98^\circ. 29' \frac{1}{2}$. B *t* $44^\circ. 22' \frac{1}{2}$. whence we deduce the Angle sought A P I $54^\circ. 7'$. as has been also said above*.

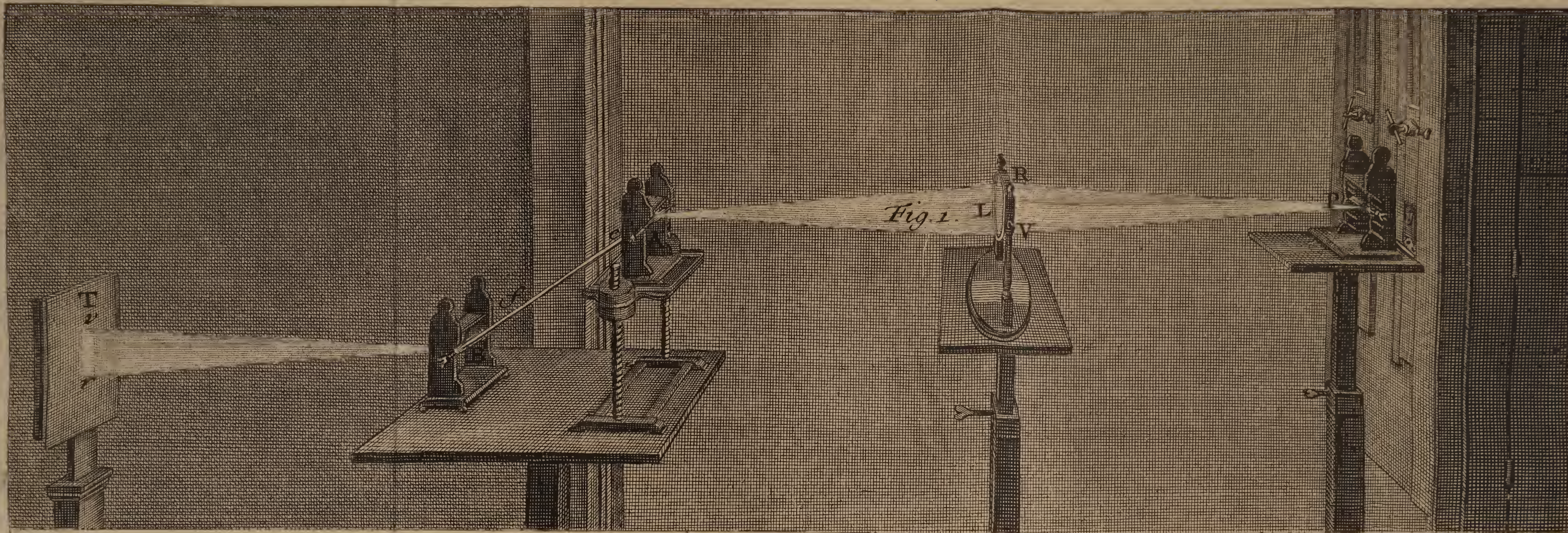
* 3594.

C H A P. XXV.

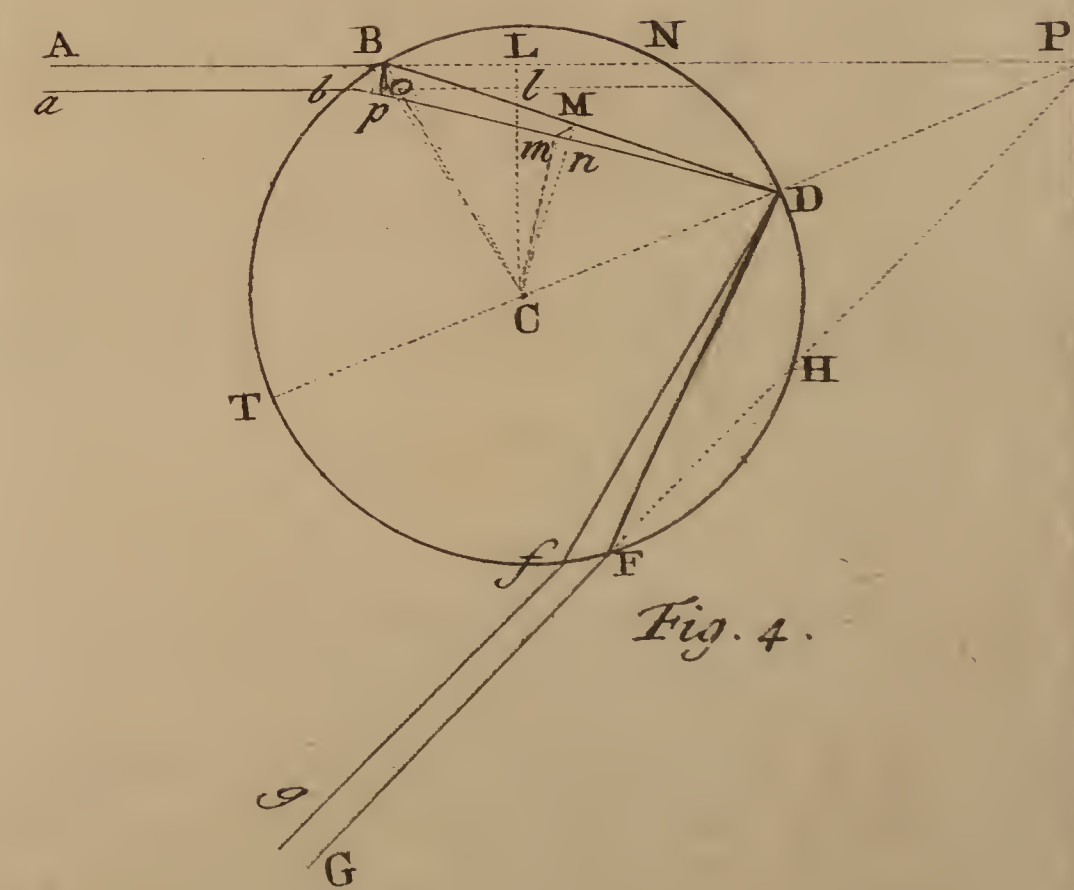
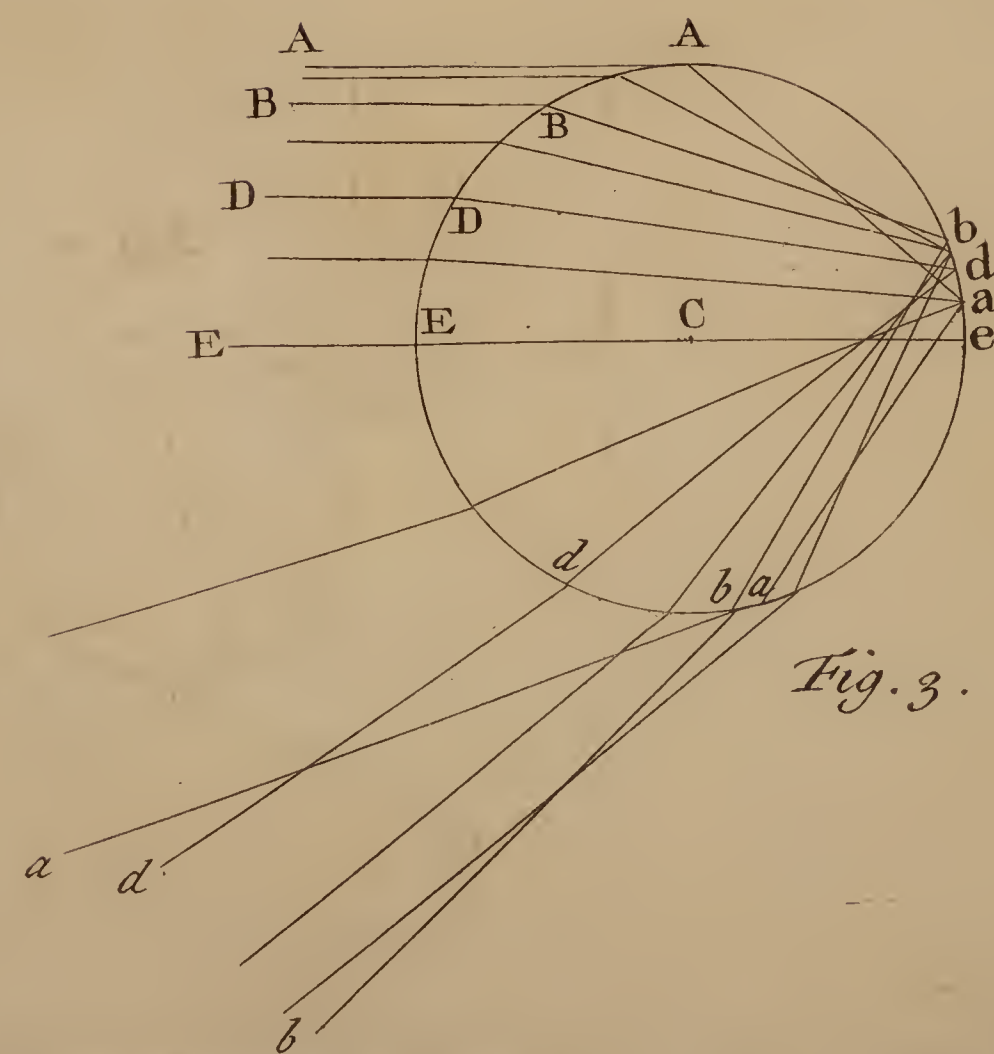
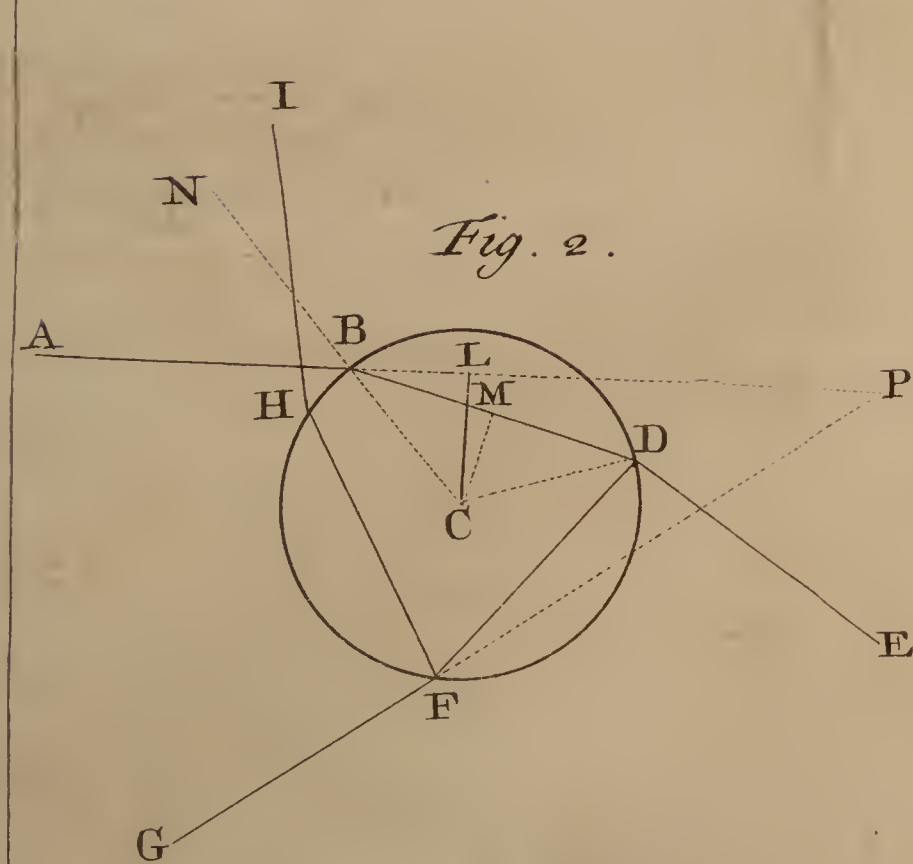
Of the Colours of thin Plates.

3619.

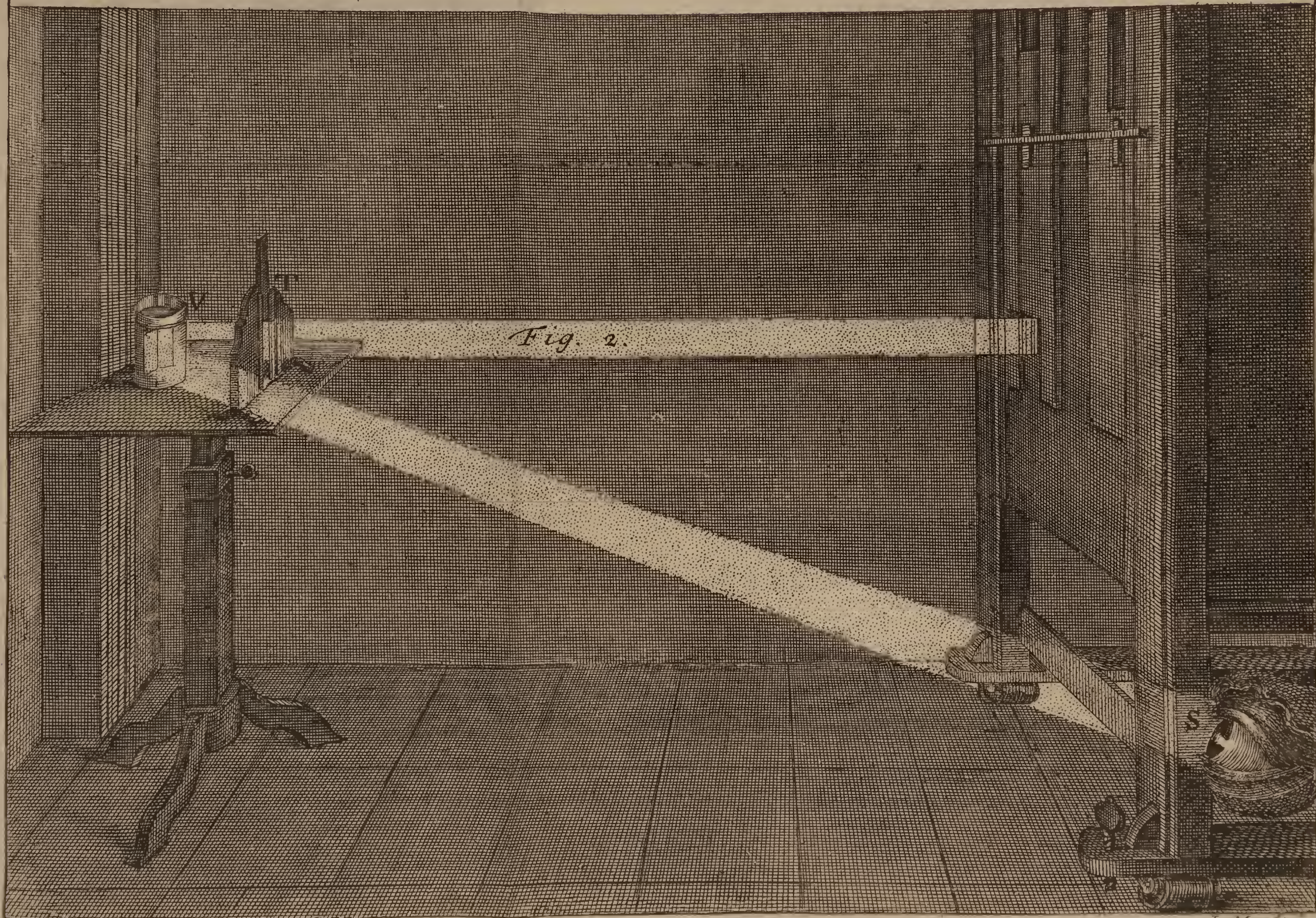
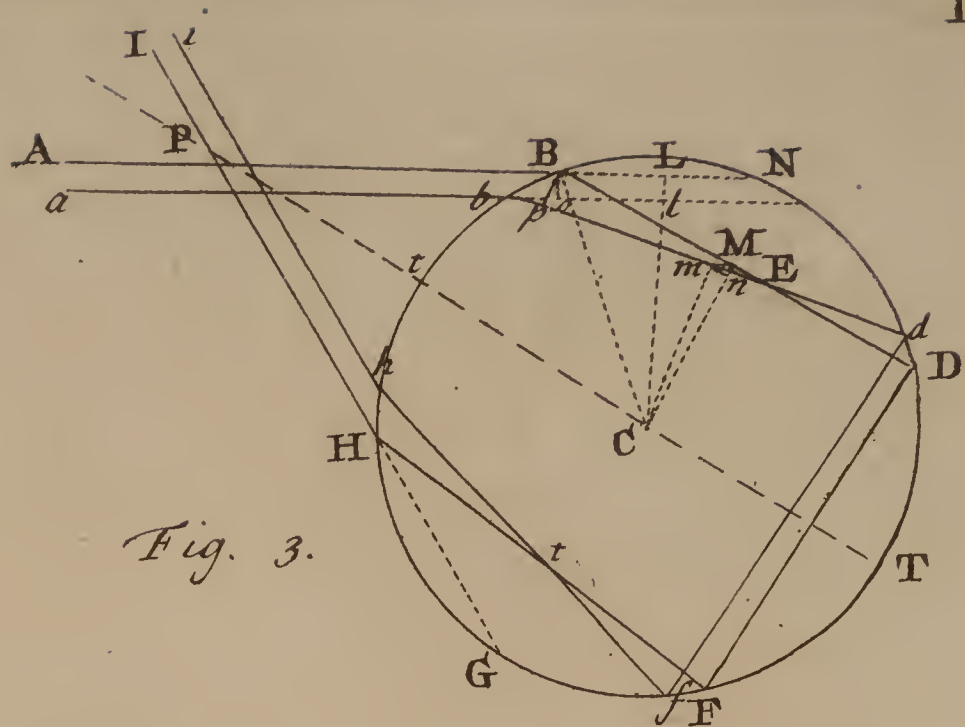
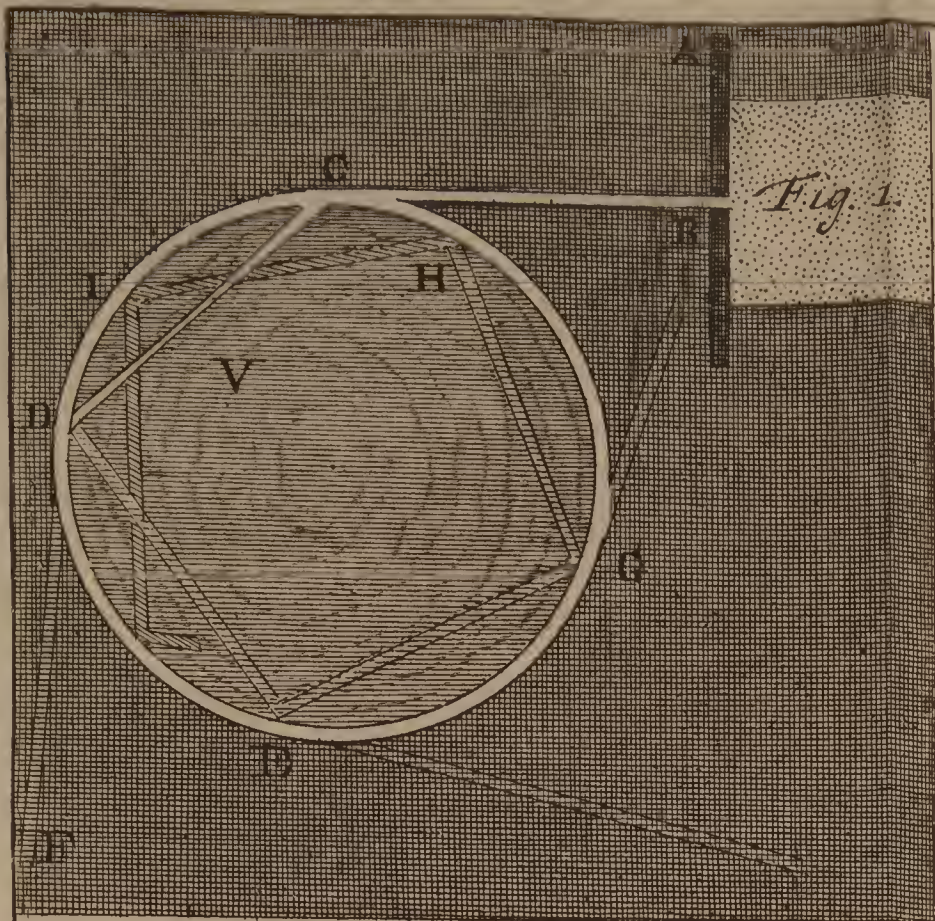
WE proceed to the Colours of natural Bodies; and first of all we think it proper to examine their thin Plates. Whoever has observed very thin Glafs, or Bubbles of Water made with
[Soap,



118



J. Mynde sc.



Soap, must have easily perceived various Colours in them, the reason of which is the wonderful Thinness of the Plates.

For the Rays of Light, by Means of a thin transparent Plate, are separated from one another; and *according to the different Thickness of the Plate, the Rays of some Colours are transmitted, and those of others reflected; and the same very thin Plate is of one Colour, when seen by the transmitted Rays, and another when seen by reflected ones.*

3620.

EXPERIMENT I.

If two object Glasses A B and C D, of long Telescopes be laid upon one another, and be pressed hard together, in the Middle, where the Glasses touch one another, you will see a transparent Spot surrounded with colour'd Circles. That this may be done regularly and conveniently, we put these upon three Feet *p, p, p*, and press together the Glasses with Screws, Plates being put between, that the said Spot may be in the Center of the Glasses. One of the Feet is represented by itself at P, L is the Plate: If the Light reflected by the Air, lying between the Glasses, comes to the Eye at O, there will appear a black Spot, and the Colours, which as you go from the Center, are so disposed, that by Reason of the Repetition of Colours, they may be referred, to several Orders, which are as follow, black, blue, white, yellow, red; violet, blue, green, yellow, red; purple, blue, green, yellow, red; green, red; which Colours are also surrounded with other Colours, growing weaker and weaker the farther they are from the Center.

3621.
Pl. 120.
Fig. 2.

3622.

EXPERIMENT 2.

If the Light passes through the Glasses, and the Plate of Air which is between into the Eyes, the Spot in the Middle, through which Rays of all Colours pass, appears white, and in receding from the Center, the Colours, which also may be refer'd to different Orders, opposite to the foregoing ones, appear according to this Series.

3623.

White, yellowish, red, black, violet, blue; white, yellow, red, violet, blue; green, yellow, red, bluish green; red, bluish green; which are also encompassed with weaker Colours.

3624.

In these two Experiments, the Orders of the Colours are easily perceived, if the Glasses of Telescopes of only thirty Feet be made use of; but the Colours are not so easily distinguished in their Orders, except there be Glasses of Telescopes of 200 Feet or more;

3625.

but these being wanting, we may distinguish the same Colours by another Method.

EXPERIMENT 3.

3626. The right-angled Prisms abovemention'd *, are joined together,
 * 3552. as was there said, without putting Papers between, as in the Experiment N^o 3570. The Surface of the Prisms are never so perfectly plane, as to touch one another every where, when applied together ; there is only immediate Contact in one Place, and there the Spot appears black by reflected Rays.

The Prisms must be so pressed together by Screws, that the Spot may be placed in the Middle of the Surfaces applied together, and the Compression may be very close ; then the Spot is surrounded by oblong Rings, in which the Colours are distinguished, where the Rings are broader, which obtains at the Extremities of the Axes of the greater Rings.

3627. If we observe the Rings, Rays being transmitted, what was
 * 3623. mentioned in the last Experiment but one *, is again discovered ; and the Colours are separated more.

3628. These Colours do not depend upon a peculiar Property of the Air ; it is well known that very thin Plates of Glass or Water, are tinged with Colours : But we see distinctly these Colours in Water, by the following Method.

EXPERIMENT 4.

3629. A thin Plate of Water is made, if the Water be made thick a little with Soap, and be blown up into a Bubble through a Pipe. A Glass Plate is applied to a black Plane, and the Bubble is put upon that, in such Manner, that it makes the Figure of an Hemisphere. This Bubble is covered by a small Glass Bell, which is very transparent, lest by the Agitation of the Air, the Colours, which are observed in this Bubble, be confused by the Motion of the Water ; such a Bubble is thinnest at Top, because the Water continually flows down towards all the Parts, and the Thickness is increased continually as you descend, and the Thickness of the whole from the same Cause, is every Moment diminished. Before the Bubble is broke, it is so thin in the upper Part, that it transmits all the Light, and appears black : If in this Case, the Bubble be observ'd by reflected Rays, whilst it is illuminated by a white Sky, and the extraneous Light is intercepted by any black Body, plac'd beyond the Bubble ; the said black Spot is surrounded

rounded by the same colour'd Rings, and disposed in the same Order, as those observed in the black Spot, in the first Experiment, As the Water descends, the colour'd Rings are continually dilated till the Bubble is broke. Care must also be taken, that extraneous Objects do not appear in the Bubble itself, as in a Mirror; for by these, the Rings are in a Manner interrupted.

EXPERIMENT 5.

If, when the Extremity of the Bubble appears by reflected Rays, 3630.
a Spectator beholds it by transmitted Rays, it will be blue; and in general, the Colours by transmitted and reflected Rays, are in the same Manner opposite to the Colours of the foregoing Experiment, as the Colours are opposite in the two first Experiments.

From these Experiments compared, it follows that *by increasing the Thickness of a very thin Plate, it's Colour is alter'd*, and indeed that *there are successively the same Alterations in the same Order, whether the Medium of which it is made, has a greater or less refracting Force*; for in a Plate of Air between the Glasses, and a Plate of Water in the Bubble, the Thicknesses of which increase, in receding from the Middle Point, the Colours are placed in the same Order. 3631.

Yet *in a more refracting Plate, a less Thickness is required, than in a less refracting one, that they may be tinged with the same Colour.* 3632.

EXPERIMENT 6.

The same Things being given, which were mentioned in the first and third Experiments of this Chapter; if a small Quantity of Water be put between the Margins of the Glasses on one Side, by little and little it penetrates between them; and in the Water there are no other Colours observed than in the Air, neither is the Order of them altered, but the Circles are contracted: When the Water has come to the Center, all the Portions of the Circles in the Water, are separated from the Portions of the Air, and reduced into a less Space. 3633.

The Colour of a Plate depends upon it's Thickness and refracting Force, not upon the Medium surrounding it. 3634.

EXPERIMENT 7.

3635. If a Plate of thin Glass, be so thin as to appear coloured, the Colours are not altered, if it be made wet; that is, if the Plate be
3636. surrounded with Water, instead of Air, *the Colour of the same Plate is so much the more vivid, as it's Density differs more from the Density of the circumambient Medium.*
3637. This is proved by Experiments already explained; for the Colours of a Plate made wet are more faint, than of the same Plate surrounded with Air. The Colours in the Plate of Water are also less vivid, which is surrounded with Glass, than that which is surrounded with Air; but Water and Glass differ less in the refracting Force, than Air and Water.
3638. *If Mediums equally differ in their refracting Force, the Colours will be more vivid, if the more refracting Medium be encompassed with the less refracting one,* for in a very thin Glass Plate, which is tinged with Colours, because of it's Thinness encompassed with
- * 362 I. Air, the Colours will be more vivid, than in the Experiment *, in which the Plate of Air is surrounded with Glass.
3639. *A Plate of the same Matter, encompassed with the same Medium,*
3640. *reflects so much the more Light as it is thinner; yet if the Thickness*
- 364 I. *be too much lessened, it does not reflect the Light.* These Things are evident from the foregoing Experiments, in which, the lesser coloured Circles, which are the thinnest too, reflect the Light the best of any; but in the Center, where the Plate is the thinnest of all, there is no sensible Reflection; as clearly appears in the fourth Experiment. In the three first, there is also a very thin Plate of Air, which does not reflect the Light, for the transparent Spot is bigger than those Parts of the Surfaces of the Glasses, which immediately touch, by the yielding of the compressed Parts inwards.
3642. *If there are Plates of the same Medium, whose Thicknesses are in an arithmetical Progression of the natural Numbers, 1, 2, 3, 4, 5, 6, 7, &c. If the thinnest of them all reflects any homogeneous Rays, the second will transmit the same, the third will reflect them again, and the Rays will be alternately reflected and transmitted; that is, the Plates, whose Thicknesses answer to the odd Numbers, 1, 3, 5, 7, &c. of the arithmetical Progression aforesaid, reflect the Rays, which the others transmit, whose Thicknesses answer to the even Numbers, 2, 4, 6, 8, &c.*
3643. This Property of the Plates, obtains in respect of any Sort of homogeneous Rays, with this Difference, that there are different
- Thick-

Thickneſſes required for different Colours, as has been already ſaid, *; the leaſt of all is for the Reflection of the violet Colour, * 3631. and the Thickneſs for reflecting the red is greateſt; if the Thickneſſes are intermediate, the Rays of an intermediate Refrangibility are reflected, that is, *as the Refrangibility of the Ray increaſes, the Thickneſs of the Plate which reflects it is leſſened.* 3644.

EXPERIMENT 8.

This Experiment is made in a dark Place, to produce the oblong Images of the Sun ſo often mentioned, upon a Paper *. Let there * 3645. be, as in N. 3621, two object Glaſſes of long Telescopes, preſſed together, but gently that the Parts may not yield inwards, and the Eye ſo diſpoſed, that the Rays proceeding from the Image may enter into the Eye, reflected ſomewhat obliquely by the Glaſſes, that the Eye may ſee all the Colours of the ſaid Image ſucceſſively, as in a Mirror; that is, that the Glaſſes may be ſucceſſively enlightened by different homogeneous Rays; which may be done by gently moving the Priſm about it's Axis, by which the Rays are ſeparated in the oblong Image. The Rings mentioned in the firſt Experiment appear, but in greater Number, and only of one Colour, becauſe of the Immutability of the Colour in the homogeneous Rays *, in the Interſtices of * 3513. thoſe Rings the Rays are transmitted, as appears from the Blackneſs; it is alſo immediately demonſtrated, if the Rays fall upon the Glaſſes themſelves; for thoſe, which paſs through the Separations of the Rings, give Circles of the ſame Colour on Paper, placed behind the Glaſſes; the Rings are the leaſt of all, when they are violet, then they are ſucceſſively dilated, conſidering the following Colours, quite to the red. Theſe Things are demonſtrated diſtinctly with the Priſms *, but the Glaſſes muſt be ſpherical, and * 2626. but a little convex, that what follows may appear.

If when the Rings are of any Colour, the Glaſſes and the Eye remaining fixed, you meaſure exactly the Diameters of the Circles, that may be conceived to be in the Middle of the Breadth of the Rings, the Squares of the Diameters will be to one another, as the odd Numbers 1, 3, 5, &c. And in the ſame Manner if the Diameters of the Circles be meaſured, which are in the Middle of every one of the Interſtices between the Rings, the Squares of their Diameters will be as the even Numbers 2, 4, 6, &c. but in Glaſſes that are ſpherical, the Squares of the Diameters are as the Thickneſs of the Plate of Air, in the aforeſaid Circle, that is, theſe Thickneſſes are as the even and odd Numbers. 3646.

DEFINITION

DEFINITION

3647. *An homogeneous Colour in a Plate of any Medium, is said to be of the first Order, if the Plate be the thinnest of all those that reflect that Colour; in a Plate, whose Thickness is triple, it is said to be of the second Order, &c.*
3648. *A Colour of the first Order is the most vivid of any, and successively in the following Orders, in the second, third, &c. it is less and less vivid*.*
- * 3639. When a Plate of Air is enlightened with heterogeneous Rays, as that between the Glasses of the Telescopes, or any Plate like it, of any other Matter, as N. 3629, several of the Rings seen in the Experiment N. 3645, are confused, and that Colour is seen,
3649. which is made of their Mixture; for the same Thickness of a Plate is often required for reflecting different Colours of different Orders: Thus a Plate which reflects the violet of the third Order, does also reflect the red of the second Order, as may be gathered from the last Experiment, if it be attentively considered: And therefore, in N. 3622. 3629. the third violet Ring is confounded with the outward Edge of the second red Ring, and a purple Colour is produced; yet all the red of the second Order is not absorbed, because the red Ring is wider than the violet Ring.
3650. *The more the Thickness of a Plate is increased, the more Colours it reflects, and various ones too, of different Orders. The violet Plate of the tenth Order, agrees with the blue one of the ninth, and the yellow one of the eighth Order, and lastly, with the red one of the seventh Order, and the Colour of the Plate consists of the Mixture of these Colours.*
3651. *If in the first and fourth Experiments of this Chapter, a Spectator looks obliquely upon the Plates, such as that made of Air, and that made of Water, the Rings will be dilated, as they are seen more obliquely, that is, in this Motion of the Eye, the Colour of the Plate is changed in a determinate Place; yet the Dilatation is greater in*
3652. N. 3621, which proves that the Colour is more changed by the Obliquity of the Rays, if the Plate be encompassed with a more refracting Medium, than if it is encompassed by a less refracting one.
3653. The Demonstration of which Proposition is easily deduced from Plate 120. the Laws of Refraction. Let L and l be thin Plates; the last encompassed with a more refracting Medium, and the first with a less refracting Medium, and let them both be of the same Thickness: If the Rays AB , ab , equally inclined to the Plates, fall
3654. upon

upon them, there will be a Refraction at L, towards the Perpendicular *, on the contrary at l the Ray is refracted from the Perpendicular †; and though BD and *bd* are equal, *bc* is longer than BC; and therefore there is a greater Change in the Motion of the Light in the Plate l than in L. * 2787.2840. * 2783.2840.

The refracting Force of the Plate L being increased, the less refracting Medium with which it is encompassed remaining, there will be a less Difference between BC and BD, and so a less Change of Colours; and if the refracting Power of the Plate be augmented, so that the refracted Rays, whatever be the Obliquity of the incident ones, shall not sensibly Differ, there will be no sensible Difference in the Colour of the Plate, whatever Situation the Eye is placed in. 3655. 3656.

From hence we deduce, that the Colour of some Plates will vary upon changing the Position of the Eye, and that the Colour of others is permanent. 3657.

C H A P. XXVI.

Of the Colours of natural Bodies.

WHAT regards the Colours of all Sorts of Bodies, may easily be deduced, from what has been already explained. 3658.

The reflected Rays are to be first examined, and the Make of the Surfaces must be inquired into.

We have shewn that the Rays of Light have Colours peculiar to themselves, and unchangeable, so as not to be changed by Reflection*.

Therefore the Rays reflected from Bodies, have a greater or less Refrangibility, according as a greater or less Refrangibility is proper to the Colour of the Body itself. * 3537. 3659.

EXPERIMENT I.

Let two square Pieces of Ribbon, or Cloth, the one red, and the other blue, be fixed in the Middle of a black Paper, and so join'd as to touch one another at their Sides. Place the Paper so, as that the Ribbons may be well enlightened by the Light which comes through a Window into a Room; if a Spectator looks at the Ribbons through a Prism, the Colours will appear separated. But the Pl. 121. Experiment answers better if it be made as the second Experiment of the twenty second Chapter; then the said Pieces of Ribbon, VOL. II. N n bon,

bon, or Cloth, are applied to the Ruler LL; also the painted Spots of the said Colours, if these be intense may be made use of: They are illustrated with Light reflected from a Mirror, the other

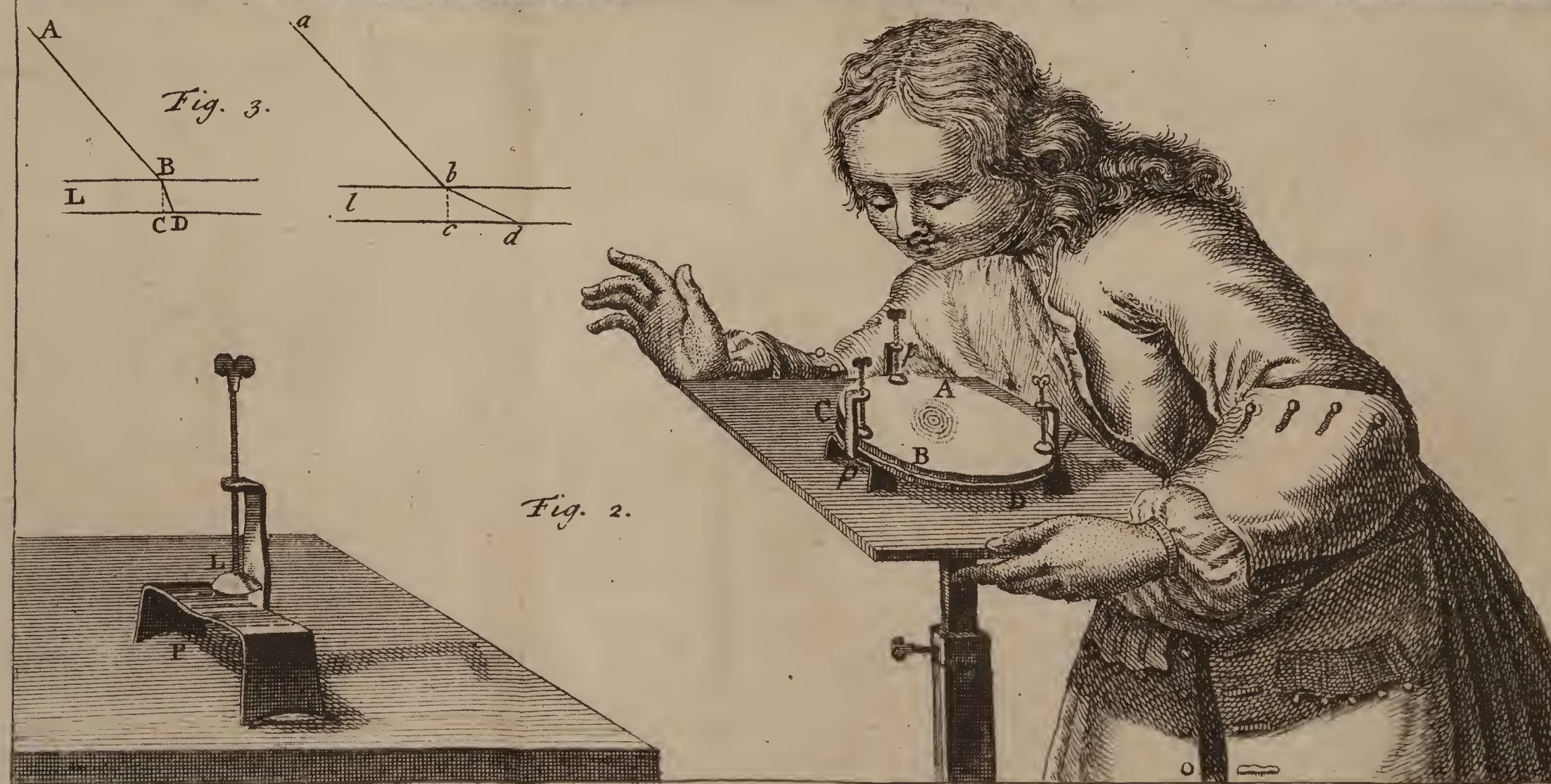
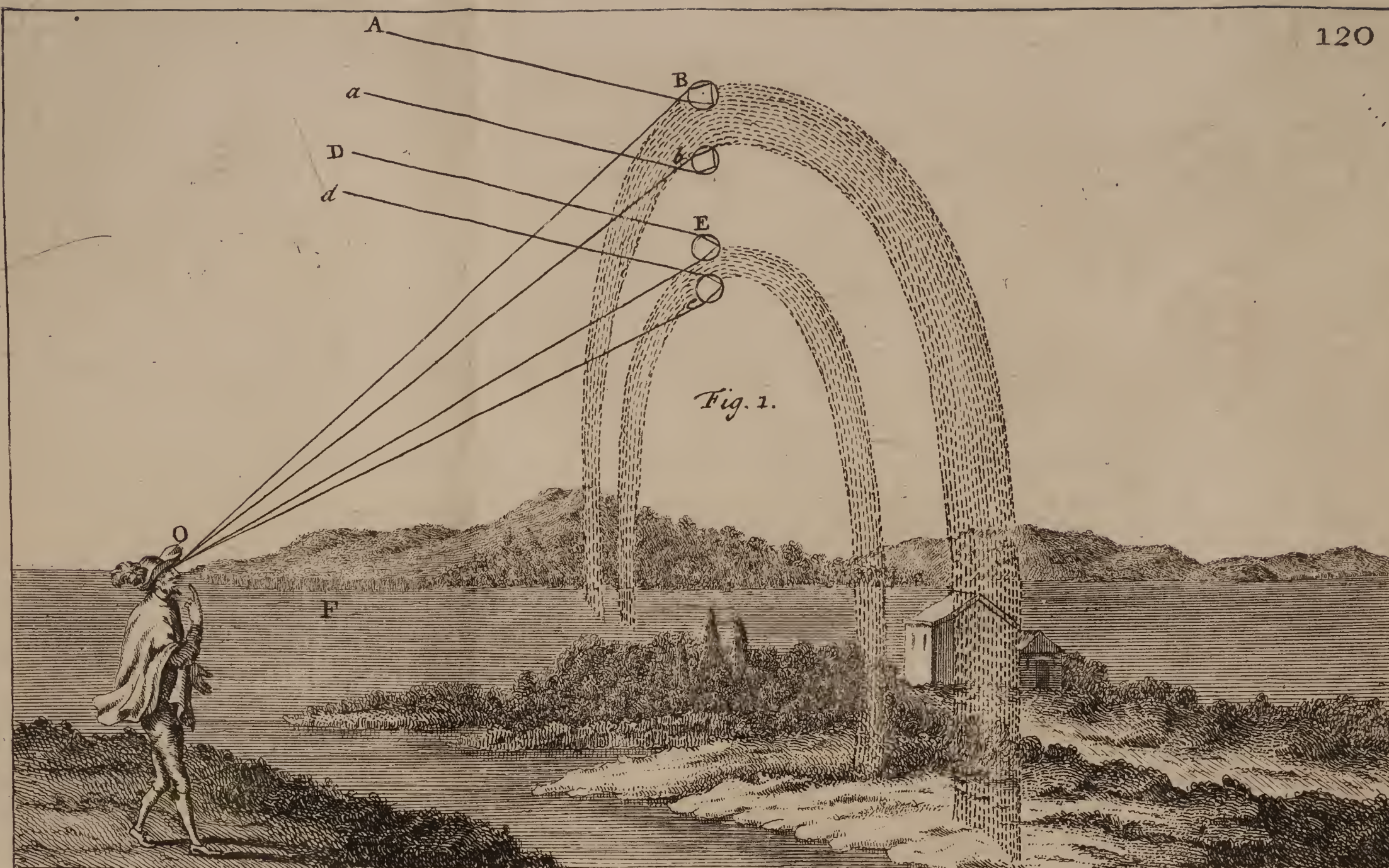
- * 3545. Things were shewn in the said Experiment *, and the Success is
 * 3543. the same *.

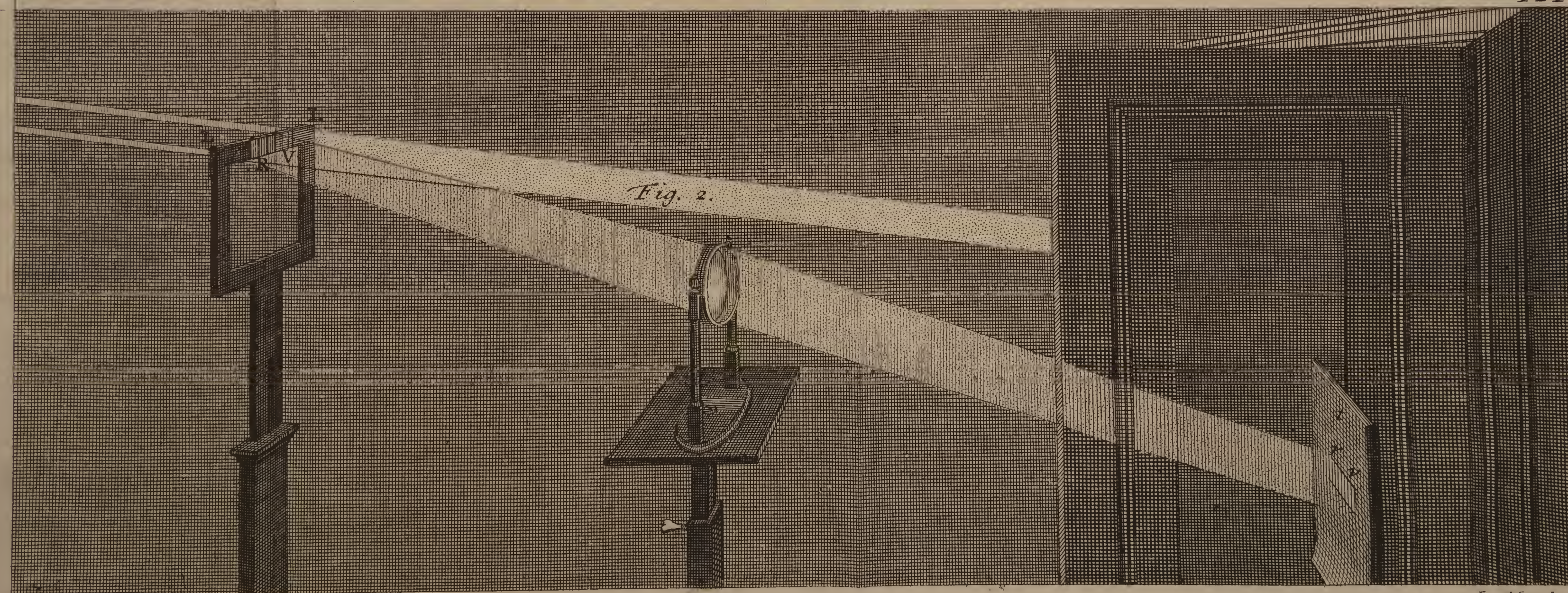
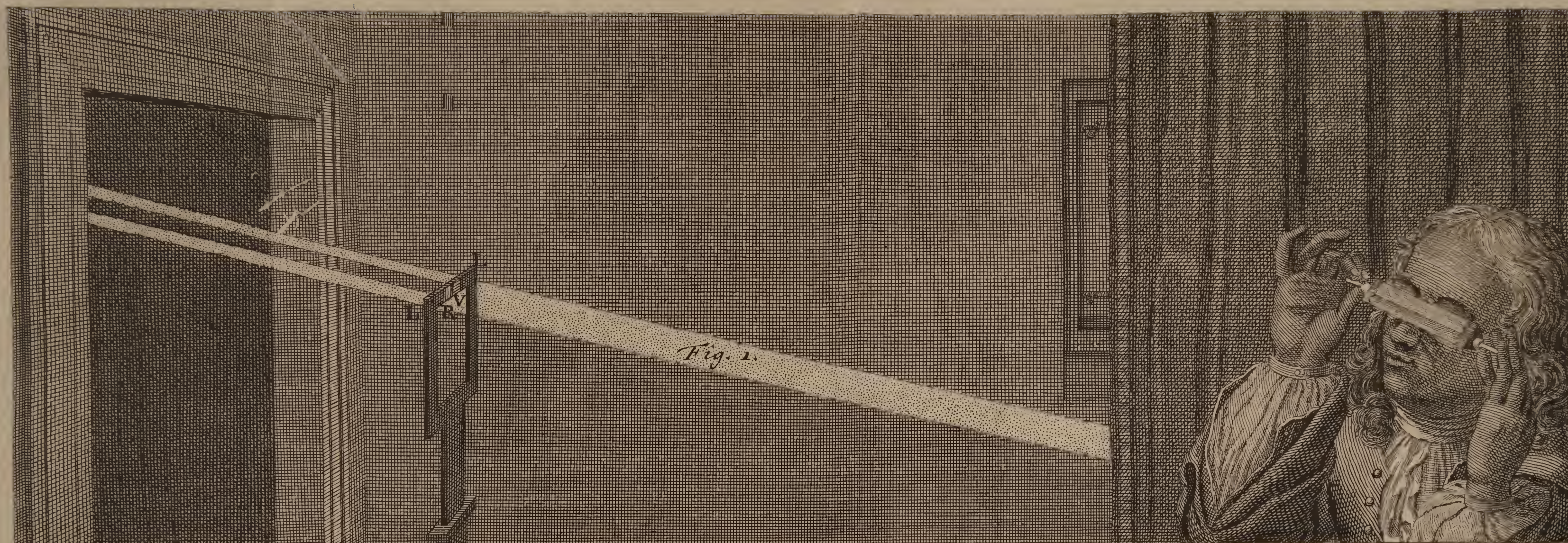
EXPERIMENT 2.

3661. This Experiment is made in the same Manner as the third Experiment of the twenty second Chapter; but instead of the black Plate 121. Lines, we make use of a black filken Thread, which we wind Fig. 2. about the Ruler LL in such Manner, that the black Lines may truly pass through the coloured Surfaces, which are illuminated with Light reflected from the Mirror, instead of the coloured Image, which is made use of in the same Experiment. The Spots are represented upon a Paper *t*, as in the said Experiment; also, as there, the white Paper must be placed at a less Distance, that we may have an exact Representation of the blue Spot: We easily discover when the Representations are exact, for the Threads appear distinct.

3662. *That Bodies have various Colours, because different Rays are reflected from Bodies of different Colours, and that a Body appears of that Colour which arises from the Mixture of the reflected Rays,* is not only deduced from the foregoing Experiments, but may also be demonstrated directly by the 1st Experiment, Chap. 22. From whence it follows, that natural Bodies reflect Rays of all Colours, but some in a greater Plenty; and these only are sensible, when Bodies are enlightened with heterogeneous Light *. The Rays which are not reflected from a Body, penetrate into it, and there suffer innumerable Reflections and Refractions, till at last they unite themselves to the Particles of the Body itself; therefore *a Body grows hot so much the sooner, as it reflects*
 * 3538. *Light* *. The Rays which are not reflected from a Body, pene-
 3663. trate into it, and there suffer innumerable Reflections and Refrac-
 * 3448. tions, till at last they unite themselves to the Particles of the Body
 3664. itself; therefore *a Body grows hot so much the sooner, as it reflects*
 * 3397. *Light in a less Quantity*; therefore *a white Body*, which reflects
 3665. almost all the Rays with which it is enlightened*, *heats the slowest,*
 * 2421. *whilst a black Body*, into which almost all the Rays penetrate, be-
 † 3563. cause only a few are reflected †, *acquires Heat sooner than any other.*

3666. In Order to determine the Constitution of the Surfaces of Bodies, upon which their Colour depends, we must consider the smallest Particles of which those Surfaces are formed; these Particles are transparent*, and are separated by a Medium of a different
 * 3443. refracting Force, from the Particles themselves*; they are also thin,
 * 3448. other-





otherwise the Surface would as it were be covered with a transparent Body *, and the Colour would depend upon the Particles underneath these: Therefore there are innumerable small thin Plates in the Surface of every colour'd Body; but by lessening the Plate, when the same Thickness is preserved, it's Properties with regard to the Reflection of Light are not alter'd; for the smallest Plate is very large in respect to the Rays of Light; therefore what has been demonstrated in the last Chapter may be applied to these Plates, in the Surfaces of Bodies, from whence we deduce the following Conclusions.

*The Colour of a Body depends upon the Thickness and refracting Force of the Parts of the Body, which are in the Surface between the Pores of the Body ** 3449. 3667. 3668.

*The Colour is so much the more vivid and homogeneous, as the Parts are thinner** 3669. * 3634. 3670. 3648. 3651.

*Cæteris paribus, the aforesaid Parts are of the greatest Thickness when the Body is red; and of the least when it is violet ** 3671. * 3643.

*The Parts of Bodies are of a much greater refracting Force, than the Medium contained in their Interstices** 3672. * 3653. 3655.

*This refracting Force is less in the Tails of Peacocks, and generally in all Bodies whose Colour differs according to the different Situation of the Eye ** 3656. 3673. * 3652. 3655.

*The Colour of a Body is more obscure and dark, when a more refracting Medium enters it's Pores *, for then the Parts, upon which the Colour depends, are encompassed by a more refracting Medium than before.* 3674. * 3656.

This is found by Experience, in all Bodies which are thoroughly penetrated by Water or Oil; when the Bodies are dry they recover their former Colour, unless in some Cases, in which some Parts are carried away, by the Action of the Water or Oil, or when some Parts of the Water or Oil are so united with the Parts of the Body, as to change the Thickness of the Plates. 3675.

From such a Cause are deduced the Changes in the Colours of some Liquors, upon mixing them with others; the saline Particles swimming in one Liquid, often unite themselves to the saline Particles swimming in one another; or from the Action of the supervenient Particles, the Particles joined together are separated; by all which the Thickness of the Particles, and with that the Colour of the Liquid is changed *. 3676. * 3631.

*The Colour of a Liquid is sometimes different, if it be seen by reflected Rays, from what it is when seen by transmitted ones: We have shewn before how this happens ** 3677. * 3622. 3624.

EXPERIMENT 3.

3678. An Infusion of *Lignum Nephriticum*, not too much tinged, appears blue by reflected Rays, but yellow when the Vial containing it is between the Eye and the Light.

EXPERIMENT 4.

3679. If Spirit of Vinegar be poured into the Infusion of *Lignum Nephriticum*, it appears yellow wheresoever it be seen.
3680. In that case the Thickness of the Particles is changed, and the Rays that were transmitted through each of the Particles are intercepted; but though the Liquor is placed between the Eye and the Light, it is seen by reflected Rays; for we may easily conceive that such Rays come to the Eye from the various Reflections which the Light suffers in the Liquid. But this Colour only is sensible, because the Rays cannot penetrate directly through the Liquid.
3681. From this we may deduce the Reason why *a coloured Liquid, in a Glass of the Figure of an inverted Cone, when it is placed between the Eye and the Light, appears of a different Colour in different Parts of the Vessel*; in the lower Part all the Rays which are transmitted through the Particles are not intercepted; then they are more and more intercepted, according as there is a greater Quantity of the Liquid between the Eye and the Light; at last they come to be all intercepted, and only those which are reflected by the Particles do penetrate into the Liquid; in which Case the Colour coincides with the Colour of the Liquid seen by the reflected Rays.
3682. Oftentimes *the Clouds appear with very beautiful Colours*. They consist of aqueous Particles, between which Air is interspersed; consequently a Cloud will be of a different Colour, *according to the various Thickness of these aqueous Particles* *.
- * 3631.

The End of the FIFTH BOOK.

Mathematical Elements
OF
NATURAL PHILOSOPHY
CONFIRM'D BY
EXPERIMENTS.

BOOK VI.

PART I. Of the System of the World.

CHAP. I.

A general Idea of the Planetary System.

HE, who attentively considers that Space can be terminated by no Bounds *, will scarce be able to deny, that the supreme Almighty Intelligence has every where manifested the same Wisdom, which he has shewn to the Inhabitants of the Earth in a small Compass. What I here call a small Compass immensely exceeds our Comprehension; yet it is but small, compared with infinite Space.

Our Earth, with sixteen other Bodies (for we have no Knowledge of any more) moves in a determinate Space; neither do these Bodies recede from, or come nearer to one another, beyond their set Bounds; and their Motions are performed according to unchangeable Laws.

3683.
27.

3684.

3685.

DEFI-

DEFINITION I.

3686. *This Collection of seventeen Bodies is called the Planetary System.* The
 3687. whole Art of Astronomy is almost employed concerning these alone; and these will be chiefly my Subject in this Book: The other Bodies that constitute the Universe are too far distant from us for their Motions (if they are mov'd) to fall under our Observations: Of these only the lucid Bodies can be perceived by us; and of these only the most remarkable ones, and which are less distant from us than the rest, even most of such as are seen by the Telescope, are invisible to the Eye.

DEFINITION 2.

3688. *All these Bodies are called fixed Stars.*
 3689. They are called fixed, because, as far as can be perceived, they keep the same Position, with respect to one another: We must take Notice of something peculiar concerning these hereafter.
 3690. But as to the planetary System: *In this we have said there are seventeen Bodies, which are all spherical: One only shines by it's own Light, the rest are opaque, and are visible only by the Light which they borrow from that.*
 3691. *The Sun is that lucid Body, and far the greatest of all in the planetary System; it is quiescent in the Middle of it, at least is agitated by a very small Motion.*

DEFINITION 3.

3692. The other sixteen are called Planets.
 3693. *These are divided into two Classes; six are called the primary Planets; ten are called the secondary Planets.* When we speak of the Planets, without any Distinction, we always understand the primary ones.
 3694. *The primary Planets move round the Sun, and are carried at different Distances from it, in Curves that return into themselves.*
 3695. *A secondary Planet revolves round a primary one, and accompanies it in it's Motion round the Sun.*
 3696. *The Planets in their Motions describe elliptic Lines**, not much
 * 625. different from Circles. *And all those Lines are fixed, at least, there is but a small Change to be observed in a long Time, in their Situation.*
 3697. *The Orbits of all the primary Planets are in such a Position that one*
 Plate 126, *of their Foci falls in with the Center of the Sun; let the Ellipse*
 Fig. 3. AB

A B *a b* represent the Orbit of a Planet, F will be the Center of the Sun.

DEFINITION 4.

The Distance between the Center of the Sun, and the Center of the Orbit, is called the Excentricity of the Planet; as F C. 3698.

*In every Revolution the Planet approaches once to the Sun, and once recedes from it; and it's greatest Distance is at *a*, the Extremity of the greater Axis of the Orbit, and it's least Distance in the opposite Extremity A.* 3699.

DEFINITION 5.

That Distance of the Planet from the Sun is called the mean Distance, which is equally different from the greatest and the least. 3700.

*At this Distance the Planet is in the Extremities B, *b*, of the smaller Axis.* 3701.

DEFINITION 6.

*The Point of the Orbit, in which the Planet is at it's greatest Distance from the Sun, is called the Aphelium; as *a*.* 3702.

DEFINITION 7.

*The Point of the Orbit, in which the Planet is at it's least Distance from the Sun, is called the Perihelium; as *a*.* 3703.

DEFINITION 8.

These Points are commonly called the Auges or Apsides. 3704.

DEFINITION 9.

The Line which joins the Apsides, that is, the greater Axis of the Orbit, is called the Line of the Apsides. 3705.

Every Orbit is in a Plane, which passes through the Center of the Sun. 3706.

DEFINITION 10.

The Plane of the Orbit of the Earth is called the Plane of the Ecliptic. 3707.

This Plane is to be continued every Way; and Astronomers consider the Position of the Planes of the other Orbits, with respect to this. 3708.

DEFINITION 11.

3709. *The Points, in which the other Orbits cut the Plane of the Ecliptic, are called the Nodes.*

DEFINITION 12.

3710. *The Line which joins the Nodes of any Orbit, that is, the common Section of the Plane of the Orbit, with the Plane of the Ecliptic, is called the Line of Nodes.*

3711. *A Planet is not carried with an equal Celerity in all the Points of its Orbit; the less it is distant from the Sun, the swifter is its Motion; and the Times, in which the several Archs of its Orbit are run through, are to one another, as the Area's formed by Lines drawn from the Planet to the Center of the Sun; the Archs A B and D d are run through in Times, which are to one another, as the Area's of the mix'd Triangles A F B, D F d.*

3713. *All the Planets are carried the same Way, and their Motion in their*
 3714. *Orbits is contrary to that Motion which we observe daily in all the celestial Bodies, by which in one Day they seem to be carried round the Earth; of which hereafter.*

DEFINITION 13.

3715. *A Motion, such as is that of the Planets in their Orbits, is said to be in Consequencia, and direct.*

DEFINITION 14.

3716. *The contrary Motion is called a Motion in Antecedentia; and sometimes retrograde.*

3717. *The more distant the Planets are from the Sun, the slower they move in their Orbits; so that the periodical Times of the most distant ones are greater, both because they have a greater Orbit to run through, and a slower Motion.*

DEFINITION 15.

3718. *The Line which passes through the Center of the Planet, and about which it moves, is called the Axis of the Planet.*

3719. *The Planets, at least most of them, and the Sun itself move round their Axes: There are two, of which, in this Respect, Astronomers have been able to make no Observations, but which, in all Probability, have this Motion.*

Chap. I. of Natural Philosophy.

281

This Motion agrees or conspires with the Motions of the Planets in their Orbits, that is, it is in Consequentia.

3720.

The Axes themselves are mov'd by a parallel Motion, so that all the Points of the Axis of a Planet describe equal and similar Lines.

3721.

DEFINITION 16.

The Extremities of the Axis are called the Poles of the Planet.

3722.

Astronomers compare together accurately enough the Distances of the Planets from the Sun, to give us an Idea of the whole System; the Dimensions of the Orbits are represented in this Scheme, in Fig. 1. which the Points N, N shew the Nodes of each Orbit.

3723.

Plate 122.

Nevertheless, we cannot compare the Dimensions of the System with any Measure that we know upon the Surface of the Earth; for no Astronomers will assert that the Observations made concerning such a Comparison are free from Error.

3724.

But, that the several Parts of the System may be compared together, we suppose the mean Distance of the Earth from the Sun divided into a thousand equal Parts, which we make use of in measuring the other Distances.

3725.

The Sun ☼, as was said before, is agitated by a small Motion in the Middle of the System: it moves round it's Axis, in the Space of 25 Days and an half; and it's Axis is inclined to the Plane of the Ecliptic, making an Angle of 87 Deg. 30 Min.

3726.

Mercury ☿, is the least distant from the Sun of any of the Planets; it's mean Distance from the Sun is 387, it's Excentricity 80, the Inclination of it's Orbit, that is the Angle, formed by the Plane of it's Orbit with the Plane of the Ecliptic, is 6 Deg. 52 Min. it performs it's Revolution round the Sun in 87 Days, 23 Hours, 15'. 38".

3727.

The next is Venus ♀, whose mean Distance from the Sun is 723, it's Excentricity 5, the Inclination of it's Orbit 3 Deg. 23 Min. It performs it's periodical Motion in 224 Days, 14 Hours, 49', 20", and it's Motion round it's Axis is performed in 24 Days, 8 Hours. It's Axis makes an Angle with the Plane of the Ecliptic of 15 or 20 Deg.

3728.

The third Planet in Order from the Sun is our Earth ☾; it's mean Distance from the Sun is 1000, it's Excentricity 16, 91, or 17 nearly, it is moved in the Plane of the Ecliptic, it's periodical Time is 365 Days, 6 Hours, 59', 14". This exceeds the tropical Year 29', 17", and the Motion about it's Axis is performed in 23 Hours,

3729.

56 Min. 4 Seconds ; it's Axis makes an Angle with the Plane of the Ecliptic of 66 Deg. 31 Min.

3730. The mean Distance of *Mars* ♂ from the Sun is 1524, it's Excentricity 141, the Inclination of it's Orbit 1 Deg. 52 Min. it's periodical Time 686 Days, 22 Hours, 29'. it's Revolution about it's Axis is performed in 24 Hours, 40 Min.

3731. *Jupiter* ♃, the biggest of all the Planets is distant from the Sun, at a mean Distance 5201, it's Excentricity 250, the Inclination of it's Orbit 1 Deg. 20 Min. the periodical Time 4332 Days, 12 Hours, 20'. 9". and it's Revolution about it's Axis S performed in 9 Hours, and 56 Min.

3732. The mean Distance of *Saturn* ♄, the most distant Planet from the Sun is 9538, it's Excentricity 547, the Inclination of it's Orbit 2 Deg. 30 Min. the periodical Time 10759 Days, 6 Hours, 36'. It is encompassed with a Ring, which does not touch the Planet, but never leaves it: This Ring is not visible without a Telescope.

3733. The mean Distance being given, if you add the Excentricity, you will have the greatest Distance ; but if you subtract the Excentricity from the mean Distance, you will have the least Distance*.

* 3698. The three Planets, *Mars*, *Jupiter* and *Saturn*, which are more distant from the Sun than the Earth, are called the *superior Planets* ; *Venus* and *Mercury* are called the *inferior ones*.

3736. *Of the primary Planets, three are accompanied with secondary ones.*

3737. Five Planets, called the Satellites, move about *Saturn*, four about *Jupiter* ; one about the Earth (viz.) the Moon.

3738. The secondary Planets, except the Moon, are not visible to the naked Eye.

3739. *The Satellites, by Lines drawn to the Center of the primary Planets, describe Area's about them, proportional to the Times ; as has been said of the primary Planets, with Respect to the Center of the Sun*.*

* 3712. 3740. *The Moon moves about the Earth in an Ellipse, one of whose Foci is in the Center of the Earth, from which the mean Distance of the Moon is 60 Semidiameters of the Earth and an half: It's Ex-*

3741. *centricity is liable to change ; the mean one is of three Semi-diameters and a third. The Plane of it's Orbit forms an Angle with the Plane of the Ecliptic of 5 Degrees, but this Inclination is not con-*

3742. *stant, or always the same. [In the Motion of the Moon round the Earth, neither the Line of the Nodes, nor the Line of the Apfides,*

is carried in a parallel Motion ; but the *Line of the Nodes*, Westward, or in *Antecedentia* ; the *Lines of the Apfides* Eastward, or in *Consequentia* ; the first performs it's Revolution in about nine Years, the second in 19. The periodical Time of the Moon's Motion about the Earth is 27 Days, and about 7 Hours, 43 Min. and it is turned about it's own Axis exactly in the same Time.

The first or inmost of the Satellites of *Jupiter* is distant from *Jupiter's* Center $2\frac{5}{6}$ Diameters of *Jupiter*, it is moved round *Ju-* 3744.
piter in one Day, 18 Hours, 27 Min. 34 Seconds. Plate 122.
Fig. 2.

The Distance of the second is four and an half Diameters of *Jupiter* : It's periodical Time is 3 Days, 13 Hours, 13', 42''.

The Distance of the third is $7\frac{1}{6}$ Diameters ; it's periodical Time 7 Days, 3 Hours, 42', 36''.

The fourth is distant $12\frac{2}{3}$ Diameters : It performs it's Motion 16 Days, 16 Hours, 32'. 9''.

The first or inmost Satellite of *Saturn* is distant from *Saturn's* 3745.
Center $\frac{3}{4}\frac{9}{10}$ of a Diameter of the Ring : It's periodical Time is one Plate 122.
Day, 21 Hours, 18', 27''. Fig. 3.

The Distance of the second $1\frac{1}{4}$ Diameter of the Ring : It's periodical Time is 2 Days, 17 Hours, 41', 22''.

The Distance of the third is $1\frac{3}{4}$ Diameter of the Ring : It's periodical Motion is 4 Days, 12 Hours, 25', 12''.

The Distance of the fourth is 4 Diameters of the Ring ; it's periodical Time 15 Days, 22 Hours, 41', 14''.

The Distance of the fifth is 12 Diameters of the Ring ; it's periodical Time is 79 Days, 7 Hours, 48'.

Concerning the Motion of these, as also of the Satellites of *Ju-* 3746.
piter about their Axis, we can hitherto determine nothing certain from Astronomical Observations.

If we take Notice of the Distances and periodical Times of the Planets, we shall find that the following Rule holds good in our System ; wherever several Bodies are moved round the same Point, that is *about the Sun, Saturn and Jupiter*, (viz.) the Squares of the periodical Times are to one another, as the Cubes of the mean 3747.
Distance from the Center.

To give a Notion of the Dimensions of the Bodies themselves in our System, we have contrived the fourth Figure, in which all 3748.
the primary Planets, and *Saturn's* Ring are described, according Plate 122.
to their Dimensions ; the Sun, whose Magnitude exceeds all the Fig. 4.
rest, is represented by the greatest Circle (Fig. 1.) that is, the Circle which terminates the Figure.

3749. These Dimensions represent the Proportions of the Bodies one to another exactly enough, if you except the Earth, which, for
 * 3724. the Reason already mentioned *, cannot be so compared with the other Bodies, as to leave no room to doubt what Proportion it bears to them.

3750. *Yet the Earth's Diameter may be measured*, and contains 3389940 Perches, each of which is equal to 12 *Rbynland* Feet; but although the Diameters of the other Planets may be compared together, and with the Sun's Diameter, yet it cannot be determined how many Feet they contain, till after Observations shall be made at a proper Time hereafter.

3751. Of the Bodies that make up the planetary System, *the Moon only can be compared to the Earth*; it's Diameter being to the Diameter of the Moon, as 73 to 20.

3752. *The other secondary Planets are not measured by Astronomers*, but it cannot be doubted, but that some of them are bigger than the Earth.

Besides the Bodies already mentioned, there are others in the planetary System, which are visible for a Time, as they come near the Sun, and then recede from it, and become invisible; they are

3753. called *Comets*. They appear most commonly with Tails, and the Tail

3754. is always turned from the Sun; in their Motion they describe Area's,

3739. by Lines drawn to the Center of the Sun, proportional to the Times,

* 3712. as has been said of the Planets*.

3755. *As to Comets, it is probable that they move in elliptic Orbits, that are very excentric*; so that they are invisible, when they are in that Part of the Orbit which is most distant from the Sun; which is deduced from the Periods of some of them, that have been observed to be pretty regular: And it is plain from Observations, that

3756. *some have described in their Motion Portions of very excentric Ellipses, in one of whose Foci was the Center of the Sun.*

3757. The Notion, that we have hitherto given of the planetary System, is founded upon astronomical Observations; and what we have already said admits of no Dispute among Astronomers, if we except what relates to the Ecliptic Line and the Motion of the Earth.

3758. Some affirm, that the Orbits of the Planets are not Elliptic, but that in their Motion they describe another oval: *Kepler* has deduced from *Tycho Brahe's* Observations, that these Lines are Elliptic; and we shall shew in the following Part, that no other Curves can be described by the Planets.

Those

Jup. cum Satell.

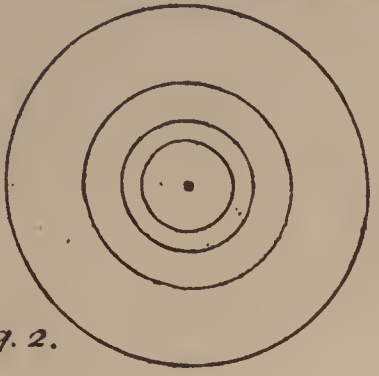


Fig. 2.



Fig. 4.

Sat. cum Satell.



Fig. 3.

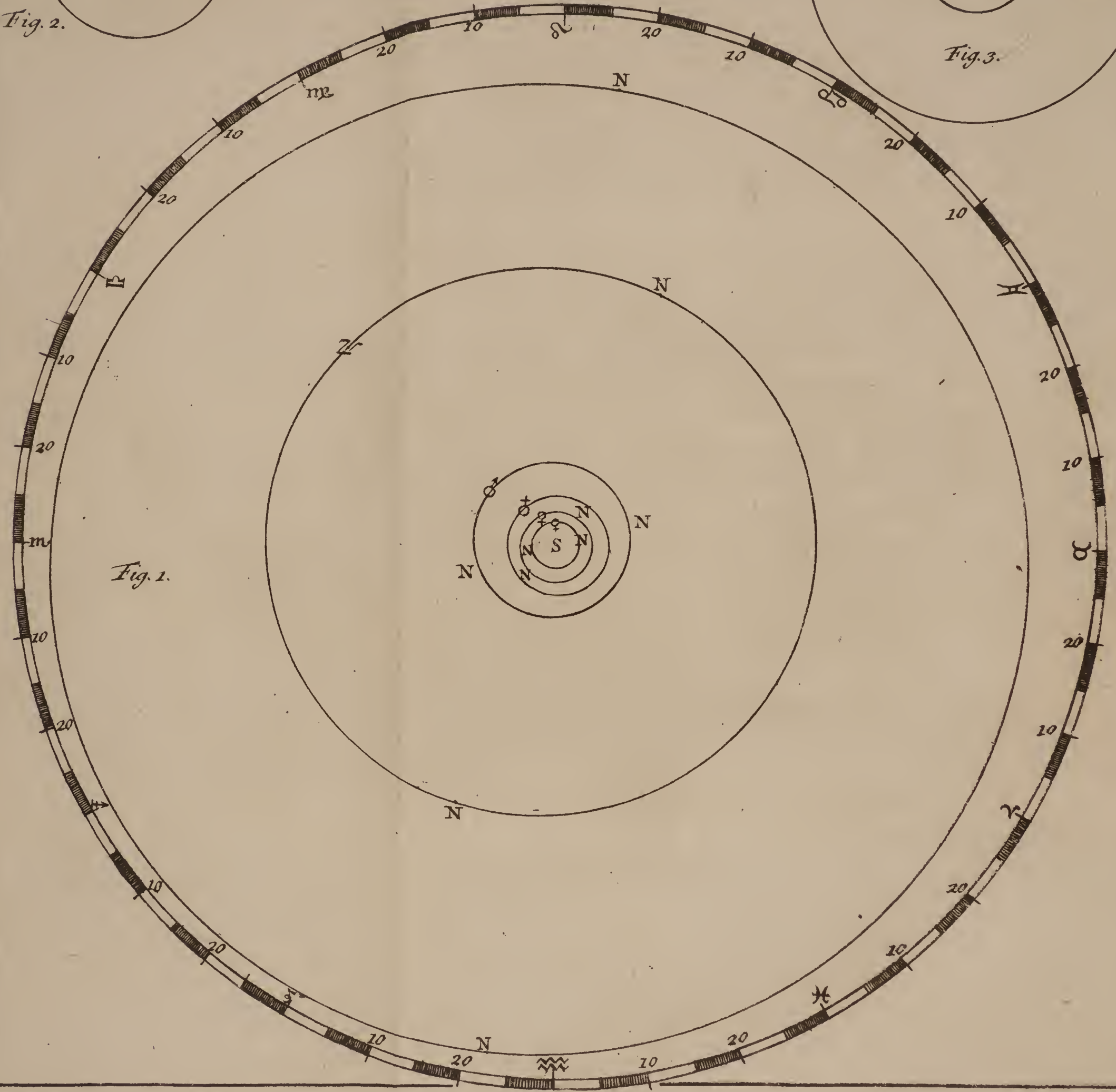


Fig. 1.

Those that say the Earth is at rest, have no astronomical or physical Argument for a Foundation of their Opinion; that is, don't reason from *Phænomena*: Neglecting the Simplicity of the System, and the Analogy of the Motions, they assert that their Opinion is not contrary to Observations; in which they err, as we shall shew in the following Part.

3759.

C H A P. II.

Concerning the apparent Motion.

WHOEVER after having read the former Chapter, looks upon the Heavens, will scarcely believe, that he beholds the System, which is explained there; and a more exact Consideration of the heavenly Motions will increase his Doubt. No Wonder, since *we can observe very little in the Heavens but false Appearances.*

3760.

The common Observer of the Heavens is a Spectator, who, thinking himself to be at rest, is carried about by various Motions, and beholds Bodies, concerning whose Distance and Magnitude he makes false Judgments. The true System of the World was unknown for many Ages, even to the most exact Observers of the Heavens.

3761.

3762.

But we must explain how all Things, which are observed in the heavenly Bodies, have Place in the System that has been explained in Respect of a Spectator upon the Earth; that is, we shall deduce the Appearances from the known Motions. Which cannot be done, unless we first lay down some general Things concerning the apparent Motion in general.

3763.

It is certain, that we have no Art, by which we can discover the true Motion, only the relative Motion can be perceived by the Senses*; and it is that only concerning which we treated in * the former Chapter: Who can reasonably affirm or deny, that all the Bodies, which are known to us, are not carried in a common Motion through the immense Spaces?

3764.

114.

The relative Motion is to be distinguished from the apparent one; for the apparent Motion is the Change which appears to be in the Situation of the Bodies, and depends upon the Change of the Picture in the Bottom of the Eye; for * Objects have the same apparent Relation to one another, as their Representations have in the.

3765.

3076.

the Eye ; for they are seen as they are painted in the Eye and the Change in that Picture, from the Motion of the Bodies, most commonly differs from the Change of the Relation between the Bodies themselves ; as follows from the Formation of that Picture.

3766. *The Heavens are nothing but an immense Space which cannot be*
 * 3462. *seen, and would appear black, * if innumerable Rays of Light*
flowing from the heavenly Bodies, did not continually penetrate
our Atmosphere. Most of them come to us from the Bodies in
right Lines. Yet a great many suffer various Reflections in the
Atmosphere, and enlighten the whole Atmosphere ; which is the
Reason that, in the Day, Bodies are enlightened, even without
the Reflection of the Clouds, to which the Rays of the Sun can-
not come directly.

3767. These Rays are heterogeneous and white ; for there are Bodies
 enlightened by these Rays which appear white : And these Bodies
 * 3574. seen through Prisms, at the Extremities are tinged with Colours,
 which does not happen in an homogeneous Colour ; * also a Cir-
 cle of white Paper of half an Inch Diameter, being put upon
 black Cloth, if it is enlightened by these Rays, it will appear ob-
 * 3501. long through the Prism * : And the same Colours, which are ob-
 served in the Rays of the Sun, are seen here in the same Man-
 ner ; all which Things would not happen, if the Air, as many
 think, was a blue Liquid ; that is, through which only the Sun's
 blue Rays, at least mostly such, pass.

3768. *When we look at the black Sky, the white Rays, beforementioned,*
enter our Eyes, whence the blue Colour of the Sky arises. Because
we are accustomed to see a Colour where there is a coloured Ob-
ject, we also refer the Colour of the Heavens to an Object ; but
 3769. *since this is seen equally towards all Parts, we conceive a concave*
spherical or rather spheroidal Surface ; in whose Center we are
placed ; we imagine this Surface to be opaque, and therefore distant
from us beyond all visible Bodies.

3770. When a Body is between a Plane and the Eye, of whose Dis-
 tance we cannot judge, the Body appears to us to be applied to
 the Plane, whatsoever the Distance is between that and the Plane ;
 for there is no Reason why the Parts of the Plane, which are
 * 3076. painted at the Sides of the Image of the Body in the Eye *, should
 not appear at the same Distance with the Body.

3771. Thence also *all the celestial Bodies* (of which the least distant
 from us, (*viz.*) the Moon) is yet so removed that we can give
 * 3116. no Judgment of it's Distance *, *are referred to that imaginary*
Sphere

Sphere above-mentioned; and they all appear equally distant, and seem to move in the Surface of a concave Sphere. So the Moon appears to be amongst the fixed Stars, although it's Distance bears scarcely any sensible Proportion to the Distance of Saturn, and the Distance even of Saturn itself is nothing compared with the immense Distance of the fixed Stars. It is no Wonder therefore, that the common People know nothing of the Magnitude of the celestial Bodies, and the Immensity of the Heavens.

We see from what has been said how the Motion of any Body being given, and the Motion of the Earth being known, the apparent Motion may be determined. 3772.

We have said that a Sphere is imagined beyond the fixed Stars, in whose Center is the Spectator *. The Orbit of the Earth is so small, in Respect of the Diameter of this Sphere, that the Center of the Sphere is not sensibly changed by the Alteration of the Place of the Spectator, whilst he is carried along with the Earth. Wherefore in all the Points of the Earth's Surface, and at any Time, the Inhabitants of the Earth imagine the same Sphere to which they refer the heavenly Bodies; and which hereafter we shall call the Sphere of the fixed Stars. 3769. 3773.

These Things being laid down, if we conceive a Line to be drawn through the Earth and a Body, which, being continued beyond the Body, cuts the aforesaid Sphere; we have a Point, to which the abovementioned Body is referred, and which is the apparent Place of that Body. 3774.

Whilst the Body, or the Earth, or both, are moved, this Line is moved also, and the apparent Motion is the Line which is described amongst the fixed Stars by the Extremity of the Line abovementioned, which goes through the Earth and the Body, whose apparent Motion is observed. 3775.

Therefore the same Appearances will follow from the Earth's being moved out of it's Place, as if the Body had been moved, and the same also may be deduced from the Motion of both. 3776.

But if the Body and the Earth be so moved, that the Line which passes through these Bodies be carried in a parallel Motion, the Body will seem to be at rest amongst the fixed Stars; because in this Case the Space, gone through by the End of the Line amongst the fixed Stars, cannot exceed the Space, gone through by the Earth; but the Line that is equal to the whole Space which the Earth can go through, at so great a Distance as the fixed Stars, is not sensible to us. 3777.

3778. *From the Motion of the Earth round it's Axis there is also produced an apparent Motion, which will be easily deduced in it's proper Place from the Foundation laid down in this Chapter.*

That the apparent Motion differs from the real, and is varied by the Motion of the Spectator, is what Sailors every Day observe.

C H A P. III.

Of the Phænomena or Appearances of the Sun, from the Motion of the Earth in it's Orbit.

Plate 123. **L** E T the Sun be at S, and the Earth in it's Orbit at T; and Fig. 1. let rs , be the Sphere of the fixed Stars; the apparent Place

3779. of the Sun will be at s^* . *When the Earth is carried in it's Orbit*

* 3774. from T to t , the Sun seems to move in *Consequentia*, and to run

* 3775. through the Arch rs^* , which measures the Angle rSs equal to

the Angle TSt , so that the Celerity of the apparent Motion of

the Sun, depends upon the Celerity of the angular Motion of

the Earth, with Respect to the Center of the Sun; which Mo-

tion increases upon a double Account; on Account of the Dis-

tance from the Sun being lessened and the Celerity of the Earth

* 3712. being increased: Both which Causes always concur*; *wherefore*

3780. *the Inequality of the apparent Motion of the Sun is sensible.*

3781. *In a whole Revolution of the Earth, the Sun also seems to run through a whole Circle.*

DEFINITION I.

3782. *This apparent Way of the Sun is called the Ecliptic Line. It is the Section of the Sphere of the fixed Stars with the Plane of*

* 3707. *the Ecliptic*, supposed to be continued to this Sphere.*

3783. This Way is divided into 12 equal Parts, each of which contains 30 Deg. these Parts are called the Signs, and are distinguished by these Names: *Aries* Υ , *Taurus* $\varnothing$, *Gemini* Π , *Cancer* $\varnothing$, *Leo* Ω , *Virgo* $\mathbb{M}$, *Libra* Ξ , *Scorpius* $\mathbb{M}$, *Sagittarius* $\mathbb{I}$, *Capricorn* $\mathbb{V}$, *Aquarius* $\mathbb{W}$, *Pisces* $\mathbb{H}$. Whence these Parts have their Names, we shall explain when we treat of the fixed Stars.

3784. *The Sun is longer in going through the six first Signs than the six last, and the Difference is nine Days.*

3785. Although a Circle has neither Beginning nor End, yet when several Points must be determined in it, some Point must be taken

Chap. 4. of Natural Philosophy. 289

taken as the Beginning; this, in the Ecliptic Line, is the first Point of Aries; we shall shew how it may be determined hereafter. It is not fixed to one Place amongst the fixed Stars: Therefore the Orbits of the Planets, which alter so little, that they may be looked upon as unchangeable *, don't preserve the same Situation, in Respect of this Point. 3786. 3696.

DEFINITION 2.

The Distance of the Sun from the first Point of Aries measured in consequentia, is called the Sun's Longitude. 3787.

The Longitudes of the other heavenly Bodies are measured after the same Manner in the Ecliptic; they are referred to that Line, by conceiving a great Circle to pass through the Body, and cut the Ecliptic perpendicularly; for the Point in which the Ecliptic is cut by this Circle, determines the Longitude of the Body. 3788.

DEFINITION 3.

The Distance of a heavenly Body from the Ecliptic is called it's Latitude. It is measured by an Arc of a great Circle, perpendicular to the Ecliptic intercepted between the Body and the Ecliptic. 3789.

DEFINITION 4.

If we imagine a Line to go through the Center of the Sphere of the fixed Stars, and perpendicular to the Ecliptic, the Points, in which this cuts the abovementioned Sphere, are called the Poles of the Ecliptic. 3790.

DEFINITION 5.

The Zodiac is a Zone which is imagined in the Heavens, which the Ecliptic Line cuts into two equal Parts, and which, on either Side, is terminated by a Circle parallel to the Ecliptic Line, and eight Degrees distant from it. On Account of the small Inclinations of the Orbits of the Planets, and the Moon to the Plane of the Ecliptic, no Bodies of the Planetary System ever appear without the Zodiac. 3791. 3792.

DEFINITION 6.

Those of them that have the same Longitude are said to be, in Conjunction. 3793.

DEFINITION 7.

3794. *Those whose Longitudes differ 180 Degrees, are said to be in Opposition.*

C H A P. IV.

Of the Phænomena of the inferior Planets, arising from the Earth's and their own Motions in their Orbits.

Plate 123.
Fig. 2.

L E T S be the Sun, A V B v the Orbit of an inferior Planet ; let T be the Earth in it's Orbit ; and $a v b$ Part of the Sphere of the fixed Stars ; the apparent Place of the Sun v *.

* 3774. If from the Earth there be drawn to the Orbit of the Planet the Tangents T A a , T B b , it is evident, that the Planet in it's apparent Motion, is never removed farther from the Sun, than the distance $v a$, $v b$; and that the Planet, as it were, accompanies it in it's apparent Motion round the Earth.

DEFINITION I.

3797. *The apparent Distance of the Planet from the Sun is called it's Elongation ; $v a$ or $v b$ is the greatest Elongation : This varies upon two Accounts ; (viz.) because the Earth and the Planet both*
* 3696. *revolve in elliptic Lines **

3799. *The Planet performs it's Revolution sooner than the Earth * ; therefore, in it's Motion, it passes between the Earth and the Sun, and then moves beyond the Sun, in Respect of the Earth : So that it is in Conjunction with the Sun in two Manners, but never in Opposition.*

3800. That we may have an Idea of the apparent Motion of the Planet, we must conceive the Lines T B b , T S v , T A a , to move along with the Earth ; so that the Points A, V, B, and v , whilst the Earth performs it's Revolution, may run through the Orbit of the Planet ; but the Planet which moves swifter, passes successively through these Points over and over.

3801. *When it is carried in it's Orbit from V to D, it seems to move amongst fixed Stars from v to d : In this Case, the apparent Motion is in Antecedentia, and the Planet is retrograde. In D it is*

3802. *said to be stationary because it appears, for some Time, in the same*

3803. *Place amongst the fixed Stars.*

This obtains, when the Orbit of the Planet, in the Place in which

which the Planet is, is so inclin'd to the Orbit of the Earth, in the place in which the Earth is, that if the Line $t d$ be drawn parallel to the Line $T D$, and at a small Distance from it, $D d$ be to $T t$ as the Celerity of the Planet in it's Orbit, to the Celerity of the Earth; these Lines are run through in the same Time*; and the Line, which is drawn through the Earth and the Planet, is carried in a parallel Motion; for which Reason the apparent Place of the Planet is not changed*. * 119. 3777

Between d and B , the Orbit of the Planet is more inclined to the Orbit of the Earth: wherefore the Extremity of the Line passing through the Earth and the Planet (although the Planet moves swifter than the Earth) is carried *in Consequentia*; towards which Part also the apparent Motion of the Planet is directed*. Yet since the apparent Motion of the Sun exceeds the apparent Motion of the Planet, the Elongation is increased, which becomes greatest, when the Planet is at B . Whilst the Planet goes through the Arc $B v$, it's apparent Motion is also *in Consequentia*, and exceeds the apparent Motion of the Sun to which it is coming, and then goes beyond it, receding from it, till it comes to A . Between A and E the Motion *in consequentia* is continued; but the Sun, whose apparent Motion in this Case is swifter, as has been explained concerning the Arc $d B$, comes towards the Planet, and the Elongation is diminished. At E , in the same Manner as at D , the Planet is stationary, between E and V it is again retrograde. * 3804. 3805. 3775. 3806.

The Orbit of the Planet is inclined to the Plane of the Ecliptic*; therefore it does not seem to move in the Ecliptic Line, but sometimes less, sometimes more distant from it, and appears to be carried in an irregular Curve, which sometimes cuts the Ecliptic. * 3706. 3708.

Let $N V N$ be the Orbit of the Planet, whose Nodes are $N N$; let S be the Sun; $T t$ the Orbit of the Earth in the Plane Ecliptic; the Earth T ; the Planet V . If $V A$ be imagined to pass through the Planet, and to be perpendicular to the Plane of the Ecliptic, the Angle $V T A$, or rather the Arc which measures it, is the *Latitude* of the Planet*: This is called the *Geocentric Latitude*, to distinguish it from the Latitude of the Planet seen from the Sun, which is called the *heliocentric Latitude*, and is in that Case the Angle $V S A$; here we speak of the *Geocentric Latitude*, because we examine the Phænomena as they appear from the Earth. * 3807. Pl. 123. Fig. 3. 3789.

When a Planet is in the Node, it appears in the Ecliptic Line; and the Curve, which is described by the Planet, by it's apparent Motion in the Zodiac, cuts the Ecliptic Line; as the Planet recedes

3809. *from the Node, it's Latitude is increased, which is also different, according to the Situation of the Earth; so the Planet remaining at V, the Latitude is greater if the Earth be at T, than if it was at t. Now, if the Earth remaining in it's Place T, we imagine the Planet to be carried from V to v; the Angle vTB will be less than the Angle VTA upon a double Account, from the Planet coming nearer the Node, and the Spectator being moved farther off.*

3810. *Now, if we consider that both the Earth and the Planet are continually moved, we shall easily conceive that the Latitude is changed every Moment from each Cause, which sometimes act contrariwise, and sometimes conspire in increasing and diminishing the Latitude; whence it necessarily follows, that the apparent Motion is performed in an irregular Curve, which, as was said before, cuts the Ecliptic as often as the Planet passes the Node, that is, twice in each of it's Revolutions; this Curve also does not recede from the Ecliptic, on either Side, beyond certain Limits in the Zodiac.*

3811. We discover also some remarkable Phænomena of the inferior
Plate 123. Planets by means of the Telescope, which are owing to their
Fig. 4. Opacity.

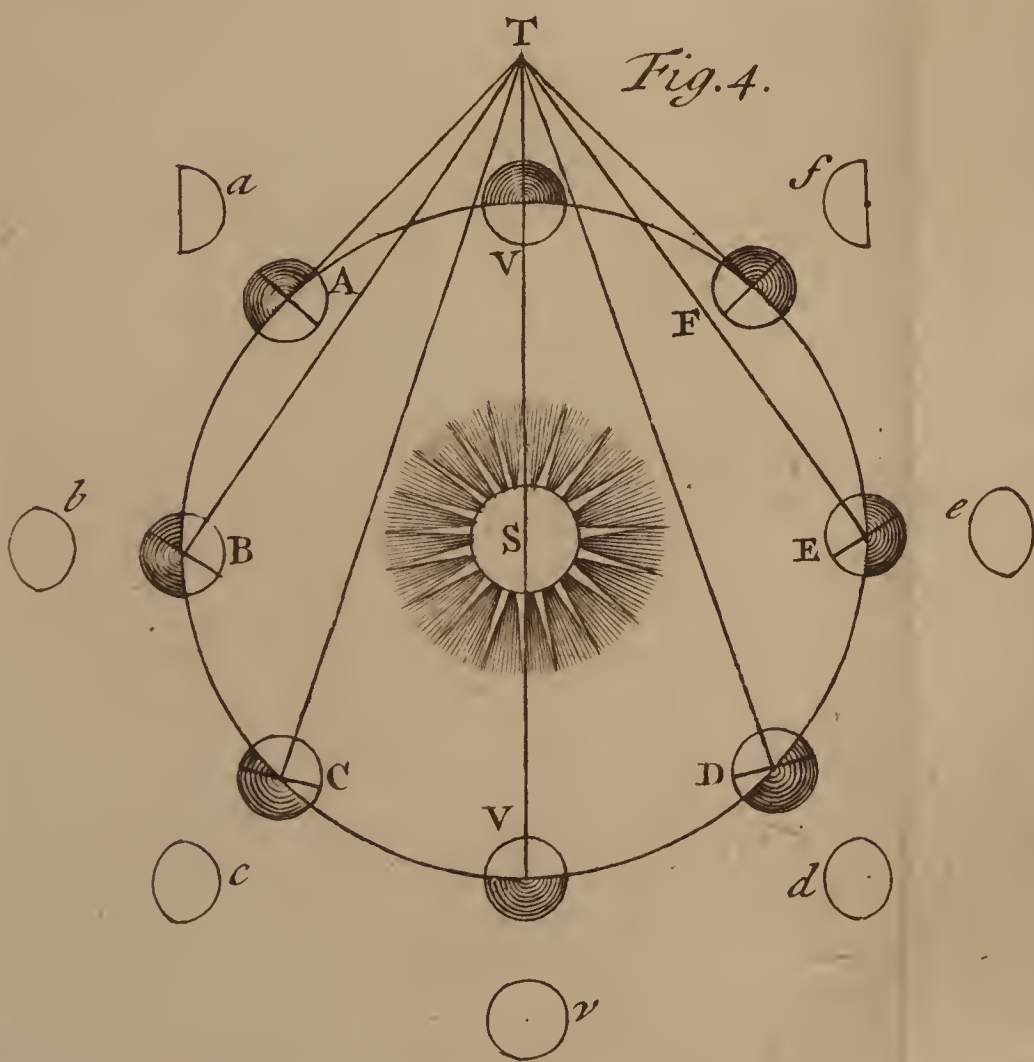
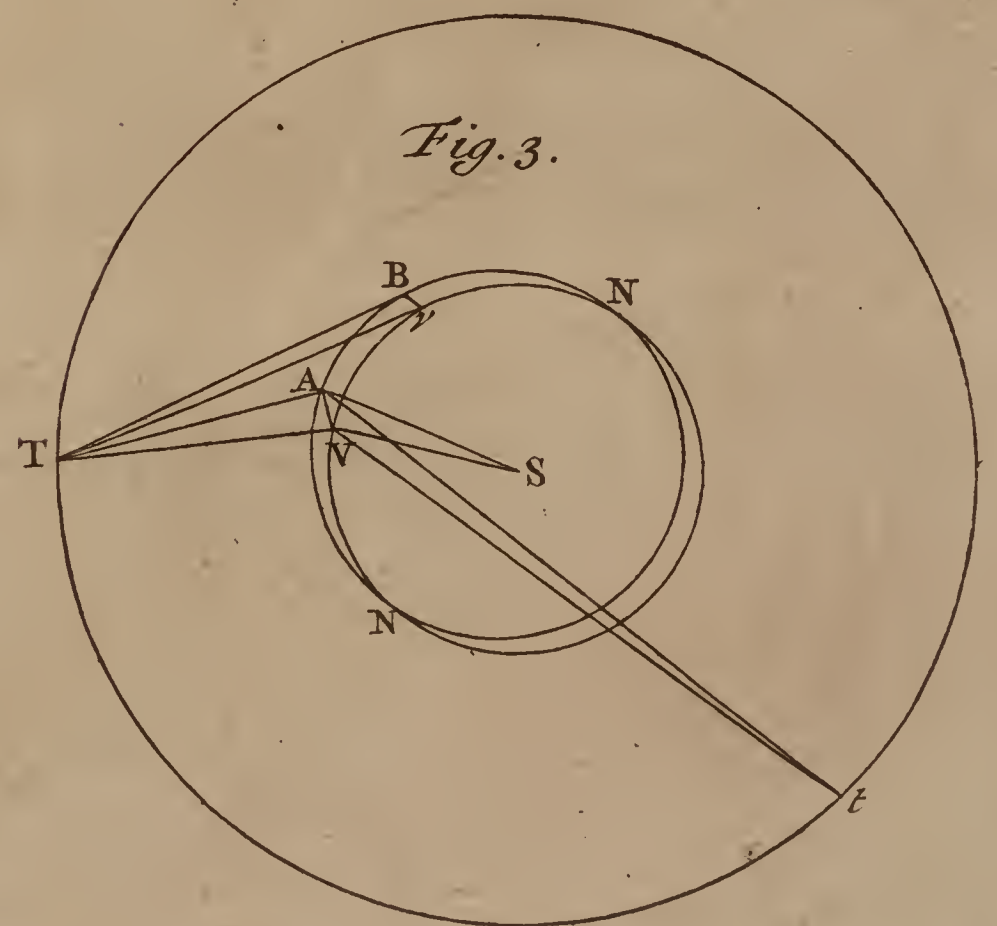
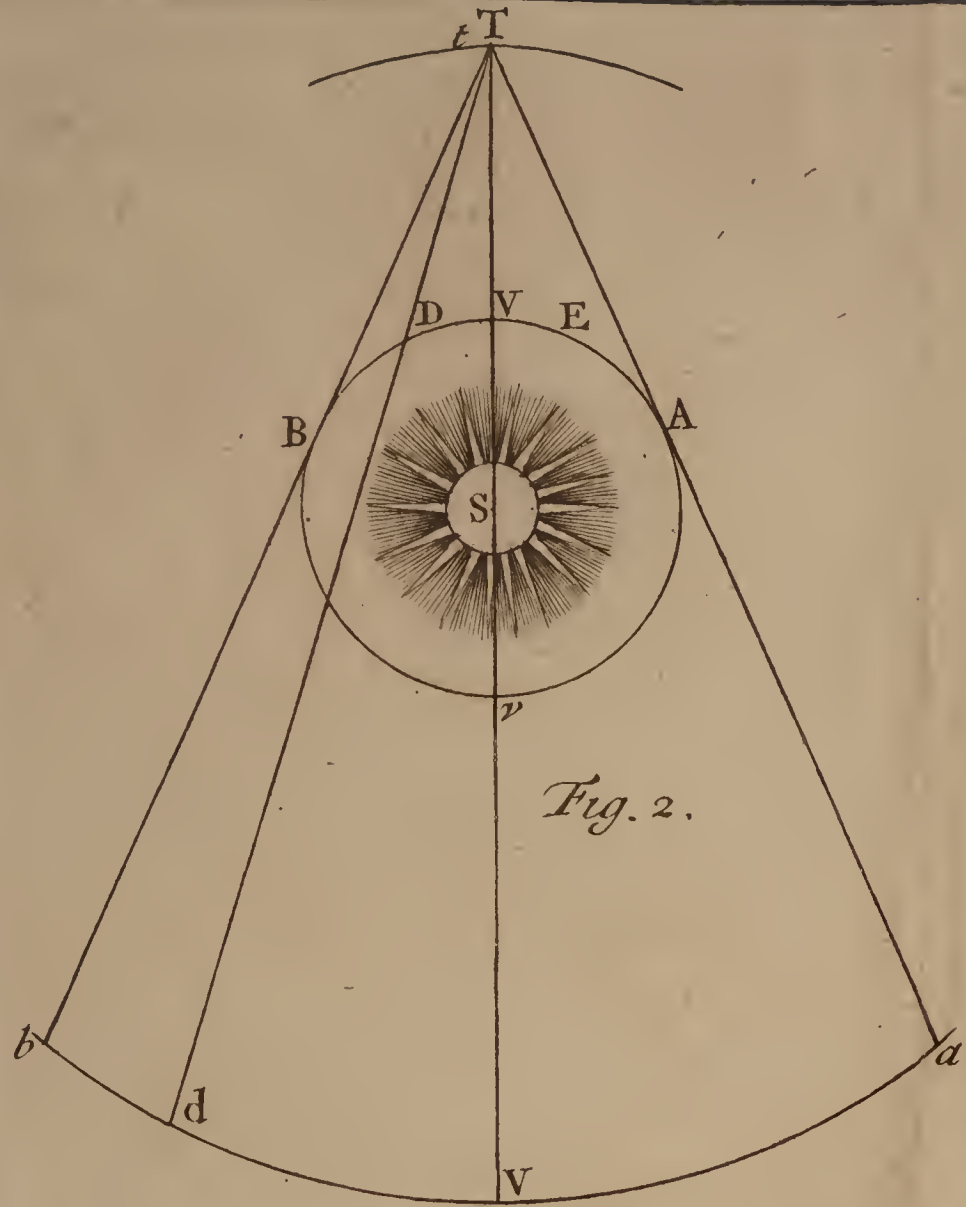
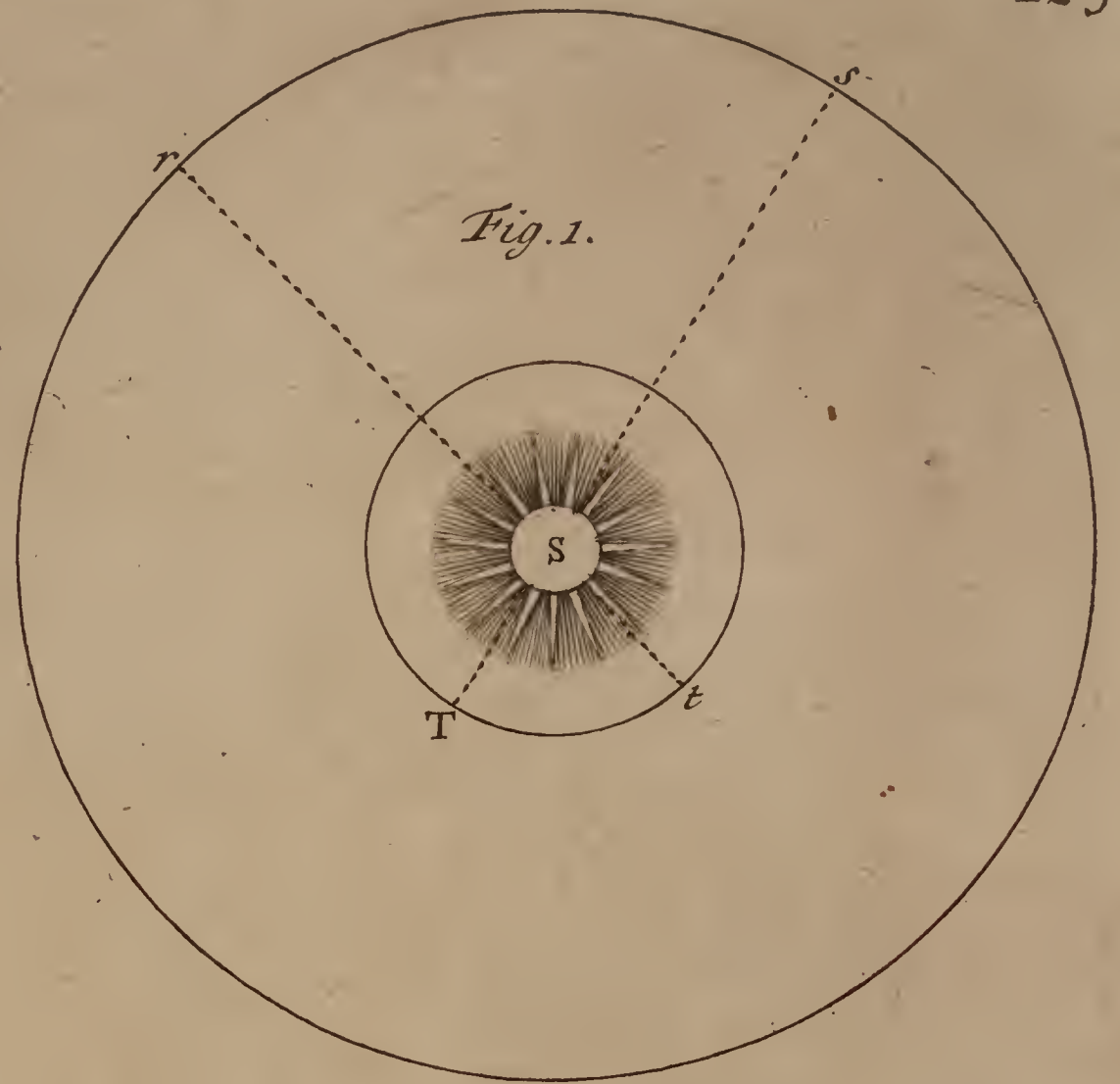
Let S be the Sun, T the Earth, A, B, C, v, D, E, F, V, an inferior Planet, *ex. gr. Venus* in it's Orbit. This Planet shines with Light borrowed from the Sun, and that Hemisphere only which is turned to the Sun is enlightened, the other Hemisphere is invisible: Therefore that Part only of the enlightened Hemisphere, which is turned to the Earth, can be seen from it; in V the Planet cannot be seen; it would appear round at v, if the Sun's Rays did not hinder it from being seen.

3812. *Going from v the Planet continually decreases; at D it has the Figure d; at e and f it is drawn as it appears at E and F, and continues to decrease, till it vanishes at V, and then again increases successively, changing it's Figure, 'till the whole enlightened Hemisphere be turned towards the Earth.*

3813. *When the Node is at V, or near it, the Planet appears in the very Disk of the Sun, and as it were applied to it, and is observed as a black Spot which moves on the Sun's Surface; in this Case, properly speaking, we don't see the Planet, but we perceive where it intercepts the Sun's Rays.*

3814. *The less distant the Planet is from the Earth, the greater it ap-*
* 3151. *pears*, and the more lucid; but as it comes nearer the Earth, the lucid Part that is visible is less, so that on one Account the*

Light



Light increases, and on another it is diminished; and there is a Distance at which the reflected Light is greatest.

C H A P. V.

Concerning the Phænomena of the superior Planets, arising from their Motions, and the Motion of the Earth in their respective Orbits.

THE apparent Motions of the superior Planets do in many Things agree with what has been explained in respect of the inferior Planets, and in many Things disagree. 3815.

They do not always accompany the Sun, but are often observed in Opposition; (as has been said of the inferior Planets) they do not always seem to be carried in Consequantia, but often appear stationary and often retrograde. 3816.

Let M be a superior Planet, for Example, *Mars* in it's Orbit, 3817.
 ATHBC the Orbit of the Earth. The periodical Time of the Plate 124,
 Earth is shorter than the periodical Time of *Mars**; therefore the Fig. 1.
 Earth in it's Motion goes between it and the Sun; in which Case, * 3717.
 the Planet appears at F, amongst the fixed Stars opposite to the
 Sun. Through M draw the Lines BM, AM, that touch the
 Earth's Orbit, which, being continued, go to G and D in the
 Sphere of the fixed Stars. Let us imagine that whilst the Planet
 is carried about in it's Orbit, those Lines are also moved; so that
 the Points A and B, in which the Lines that go through the Pla-
 net touch the Orbit of the Earth, perform a Revolution in the
 periodical Time of the Planet. Now since the Earth revolves fas-
 ter, it passes through the Points A and B in it's Motion. In this
 Motion the apparent Place of the Planet, seen from the Earth, is
 not removed from the Place of the Planet seen from the Sun be-
 yond FD and FG. Let T be such a Point in the Orbit of the
 Earth, that the Line tm , being drawn, may be parallel to TM;
 Let Tt be to Mm , as the Celerity of the Earth to the Celerity
 of the Planet; in which Case these small Lines are gone through
 in the same Time*; in the mean Time the Planet seems to be at * 119.
 rest*, and is said to be stationary. In the same Manner it is sta- * 3777.
 tionary when the Earth is at H. In the Motion of the Earth be-
 tween T and H, the Planet appears to move in *Antecedentia* from E
 through

through F to I, and is said to be retrograde ; whilst the Earth goes through the rest of it's Orbit HBCAT the Planet is direct.

3819. *The Phænomena, which relate to the Latitude, are like those which*
 * 3806. *have been explained, in respect to the inferior Planets*.*

3820. *Jupiter and Saturn encompass the Orbit of the Earth at a great Distance ; wherefore almost their whole Hemispheres, which are enlightened by the Sun, are visible from the Earth ; and therefore these Planets always appear round.*

3821. *Because Mars is less distant, it appears a little gibbous, between the Conjunction and Opposition with the Sun.*

C H A P. VI.

Concerning the Phænomena of the Satellites, from their Motion in their Orbits Where we shall speak of the Eclipses of the Sun and Moon.

3822. **T**HE Satellites of Jupiter and Saturn do always accompany their Primaries in their Motion, and never appear to recede from them beyond certain Limits on either Side, which may be easily determined from their Distances from their Primaries ; and they are alternately carried in *Antecedentia* and in *Consequentia*. Sometimes

3823. all of them are on the same Side of the primary Planet, and sometimes the Primary is observed to be between them ; *Jupiter's Satellites are all always in the same Right Line, or very little distant from it.* All which Things may be deduced from this, that the Motion about the primary Planets is performed in Planes that make small Angles with one another, and with the Plane of the Ecliptic.

3824. All these Satellites of Saturn or Jupiter are not always visible at the same Time, when they are between their Primary and the Earth, they cannot be distinguished from their Primary : Sometimes they are hid by their Primary, and often immersed in it's Shadow.

DEFINITION I.

3825. *Such an Immersion in the Shadow is called an Eclipse of the Sa-*
 Plate 85. *tellite.*

Fig. I. We have treated of this before *. Whilst the Secondary moves from E to F it undergoes an Eclipse ; and, not being enlightened by the Sun, becomes invisible. If we consider the two first Satellites of Jupiter, only the Immersion into the Shadow at E is vi-

* 2624.

2625.

fible, when the Earth is in the Part C D A of it's Orbit. On the contrary, the Emerfion only can be feen if the Earth be in the Part A B C.

Amongft the Bodies that accompany *Saturn*, we have faid that there is a *Ring* *; concerning which it is to be obferved, that an *
 Obferver upon the Earth *never fees it wider than Saturn's Diameter, and that fometimes it is invifible*; namely, when the Plane of the Ring being continued, goes through the Earth; for the Thick-
 nefs of the Ring is not fenfible. 3827.
 3732.

The Ring is alfo invifible, when it's Plane continued, paffes be- 3828.
 tween the Earth and the Sun; for then the enlightened Surface of the Ring is turned from the Earth.

In each cafe *Saturn* appears round, yet in the laft Cafe, by rea- 3829.
 fon of the Rays that are intercepted by the Ring, there appears a black Belt upon the Surface of the Planet, like that which is oc-
 cafioned by the Shadow of the Ring.

The Phænomena of the Earth's Satellite, namely, of the Moon, 3830.
 are very remarkable in refpect to us, and therefore particularly to be explained.

*It is very often in Conjunction with the Sun, and as often in Oppo- 3831.
 fition to it, but not at every Revolution of the Moon in it's Or-
 bit; for whilft the Moon, after one entire Revolution of 27 Days,
 and 7 Hours, returns again to the Place, amongft the fixed Stars, in
 which it was in Conjunction with the Sun, the Sun is gone from
 that Place, and is about 27 Deg. diftant from it* *: therefore it does * 3729.
 not reach the Sun till after fome Days; *the neighbouring Conjun- 3781.
 ctions are twenty nine Days and a half diftant from one another.* 3832.

DEFINITION 2.

*The Lunar periodical Month is the Time of one Revolution of the 3833.
 Moon in it's Orbit.*

DEFINITION 3.

*The Moon's fynodical Month, or a Lunation, is the Time that the 3834.
 Moon fpend between the two next Conjunctions with the Sun.*

*The Moon is invifible in it's Conjunction with the Sun, becaufe the 3835.
 enlightened Hemisphere is turned from the Earth. Let T (Plate
 124. Fig. 2.) be the Earth, N the Moon between the Sun and
 the Earth, the enlightened Hemisphere will be *m l i*, which cannot
 be feen from the Earth.*

Whilft

3836. *Whilst the Moon is carried in it's Orbit, from the Conjunction to the Opposition, the enlightened Part, which is directed towards the Sun, does continually become more and more visible to the Inhabitants of the Earth; and in the Points A, B, C, the Moon does successively acquire the Figures $a b c$.*

3837. *At P, in it's Opposition with the Sun, it appears round; then going through D, E, F, it decreases as it is represented at d, e, f .*

DEFINITION 4.

3838. *The Conjunction of the Moon with the Sun is called the new Moon. After the Conjunction, the Moon is as it were renewed.*

DEFINITION 5.

3839. *The Opposition of the Moon with the Sun is called the full Moon, because the whole Moon appears enlightened.*

DEFINITION 6.

3840. *The Conjunction and Opposition of a Satellite with the Sun, are called by the common Name Syzygies.*

3841. *At A and F, the dark part of the Moon is a little enlightened by the Rays that are reflected from the Earth; and therefore it is seen by a Spectator to whom the Sun is not visible, that is, in the first Case, after the setting of the Sun, and in the second, before it's rise.*

DEFINITION 7.

3842. *When the Light of the Sun is intercepted by the Moon, so that, in respect of any Observer upon the Earth, the Sun is partly or wholly covered, the Sun is said to undergo an Eclipse.*

3843. *Properly speaking, this is an Eclipse of the Earth, on whose Surface the Shadow or Renumbra of the Moon falls.*

DEFINITION 8.

3844. *An Eclipse of the Moon is the Obscuration of the Moon by the Shadow of the Earth.*

3845. *The Eclipse of the Sun is never observed except at the Time of the New Moon.*

3846. *The Moon is never eclipsed but at the Time of the full Moon.*

3847. *Yet the Luminaries are not eclipsed at every one of the Syzygies,*

* 3742. *because the Moon does not move in the Plane of the Ecliptic*, in which the Sun and Earth always are; wherefore upon Account of*

Account of the Moon's Latitude, it's Shadow, at the new Moon, often does not touch the Earth ; and itself, at the full Moon, passes beside the Shadow of the Earth.

But *when the Moon* has no Latitude, or but very little, that is, when it *is in the Node, or near it, at it's Syzygies, an Eclipse is observed*; in that Case the Moon appears to be in the Ecliptic, or very near it ; and this it is that has given the Name to that Line. 3848.

That what relates to the Eclipse of the Moon may appear the more plainly, let O O be the Way of the Moon, R R the Plane of the Ecliptic ; the Center of the Earth's Shadow is always in it *; N is the Node of the Moon's Orbit. 3849. Pl. 125. Fig. 1. * 3707.3709.

If the Earth's Shadow be at A, the Moon that goes by at F will not be darkened. 3850.

If the Moon be the less distant from the Node at the full Moon, as at G, the Shadow of the Earth is at B, and *the Moon is darkened in Part ; this is called a partial Eclipse.* 3851.

If supposing the Shadow at D, the Moon be full, *the Moon will be wholly darkened at I, it runs into the Shadow at L, and goes out of it at H ; and the Eclipse is said to be total.* 3852.

The Eclipse is said to be central, when the Center of the Moon goes through the Center of the Shadow, which only happens in the very Node N. 3853.

We have hitherto spoken of the Shadow of the Earth ; because, when we mention the Earth, we understand it's Atmosphere which is joined to it, of which we have spoken elsewhere *: *The Shadow of the Atmosphere is properly considered in lunar Eclipses*; for the Shadow of the Earth itself does not reach the Moon. 3854. * 2080.

Let T be the Earth, the Atmosphere about it FDGGDF. The Sun's Rays B D, B D, touching the Atmosphere ; these go straight on, and terminate the Shadow of the Atmosphere, out of which if the Moon be, it is immediately enlightened by the Sun's Rays ; but it is not enlightened in the same Manner all the while it is between BD and BD. 3855. Plate 124. Fig. 3.

*The Rays which enter the Atmosphere obliquely are refracted** ; and as they come towards the Earth, they continually penetrate into a Medium which is denser and denser †, and therefore are every Moment inflected*, and *move in Curves.* So the Rays E F, E F, penetrate the Atmosphere in the Curves FG, FG, that touch the Earth. All the Light between E F, E F, is intercepted by the Earth, and the Rays G A, G A, terminate the Earth's Shadow. 3856. * 2778. † 2110. * 2787.2829.

3857.

The Light between EF and BD, being refracted by the Atmosphere, is scattered between GA and BD continued, and beyond A the Point of the Earth's Shadow, the Lights that come from all Parts are confounded, but are continually weaker and weaker the farther from the Earth : So that *the Shadow of the Atmosphere is not a perfect Shadow but a weak Light* whereby the Moon is visible in an Eclipse.

3858.

3859.

The Shadow of the Atmosphere is conical, because the Sun's Diameter is greater than the Diameter of the Atmosphere, which is scarce bigger than that of the Earth ; and this Cone to Mars, as appears from immediate Observations ; but the Shadow of the Diameter, in the Place where it is cut by the Moon's Orbit, is scarce one fourth less than the Diameter of the Earth.

3860.

With the same Reasoning that we have proved, that the Moon comes into the Shadow of the Atmosphere, when the Moon in it's full is in the Node or near it ; it is also proved, that the Moon's Shadow falls upon the Earth *at the new Moon, when the Moon is in the Node, or near the Node* ; therefore in that case *the Sun undergoes an Eclipse* ; concerning which, several Things are to be observed.

3861.

3862.
Pl. 124.
Fig. 4.

Let S be the Sun, L the Moon ; let the Shadow of it fall upon any Plane GH. This Shadow is encompassed with a Penumbra, for beyond M and E that Plane is enlightened by one entire Hemisphere of the Sun ; as you go from M to H, and from E to G, the Light is continually diminished, and near G and H the Rays come to the Plane only from a small Part of the Sun's Surface.

DEFINITION 9.

3863.

This diminished Light, which encompasses the Shadow GH every Way, is called the Penumbra.

3864.

In the Eclipse of the Moon, the Shadow of the Earth is encompassed with *the like Penumbra*, but this is only sensible near the Shadow, and therefore *has but a small Breadth* ; but if an Observer be placed upon a Plane upon which the Shadow falls, he *may observe the whole Penumbra* ; as is the Case *in the Eclipse of the Sun*. An Observer I or F can only see the Semi-diameter of the Sun, the rest of the Diameter is hid by the Moon ; and going from M towards H, the Sun is continually more and more hid by the Moon, till it becomes wholly invisible in the Shadow itself.

3865.

Chap. 7. *of Natural Philosophy.* 299

Hence it follows, *that there is a solar Eclipse, though the Shadow of the Moon does not touch the Earth, provided the Penumbra comes to it's Surface. And also, that the Eclipse is not observed in all the Places in which the Sun is visible; and that it is different, according as the Shadow, or a different Part of the Penumbra goes through the Place, in the Places in which it is observed.* 3866. 3867. 3868.

But the Eclipse of the Moon is every where the same, where the Moon is visible, during the Eclipse. 3869.

But when the Shadow itself of the Moon falls upon the Earth, the Sun's Eclipse is said to be total; if only the Penumbra reaches the Earth, it is said to be partial; and this is what happens when we consider an Eclipse in general. 3870.

But as to particular Places, it is said to be total in those Places where the Shadow passes; central, in those where the Center of the Shadow passes, that is, where the Center of the Moon covers the Sun's Center; and lastly, partial, where the Penumbra only goes by; and this is drawn in Fig. 5. 3871.

The wider the Shadow GH is, the more Places is the Eclipse of the Sun Total in, and the longer is the Sun wholly obscured. But the Breadth of the Shadow is different according to the different Distances of the Moon from the Earth, and of the Earth from the Sun. 3872. Plate 124. Fig. 4.

If there be an Eclipse of the Sun, supposing the Earth in the Perihelion and the Moon in the Apogæum, that is, at the greatest Distance from the Earth, the Shadow of the Moon does not reach the Earth, and the Moon does not cover the whole Sun; such an one is called an annular Eclipse, and is represented in Fig. 6. 3873.

C H A P. VII.

Of the Phænomena arising from the Motion of the Sun, the Planets, and the Moon about their Axes.

TH E Sun's Motion about it's Axis is sensible, by observing the Spots, which are seen very often upon the Sun's Surface: These Spots seem to change their Figure and Situation every Day, and sometimes to move swifter, sometimes slower; all which Things may be easily deduced from the Motion of the spherical Surface; and the Sun, which if it was not moved by such a Motion, would only once in a Year successively turn it's whole Surface 3874.

to the Earth, now shews it to the Inhabitants of the Earth in less than the Space of one Month.

3875. Such like Phænomena arise from *the Rotations of Jupiter, Mars and Venus, about their Axis*, which Motions become sensible, by observing the Spots in the Surface of the Planets.

3876. Whilst the Earth is moved round it's Axis, the Observer, who is carried round, imagines himself to be at rest, and all the heavenly Bodies to be in Motion.

DEFINITION 1.

3877. *The Points, in which the Axis of the Earth, being continued both Ways, touches the Sphere of the fixed Stars, are called the Poles of the World.*

DEFINITION 2.

3878. *The apparent Motion, arising from the Motion of the Earth about it's Axis, is called the Diurnal Motion.*

DEFINITION 3.

3879. *A Plane is conceived to pass through the Center of the Earth, perpendicular to it's Axis, and continued every Way, and the Circle in which it cuts the Sphere of the fixed Stars is called the cœlestial Æquator.*

3880. *In the Motion of the Earth, round the Sun, the Æquator is moved;*

* 3721. *but since the Plane of this Circle is carried by a parallel Motion*,*

† 3777. *the cœlestial Æquator is not moved†.*

DEFINITION 4.

3881. *Circles whose Planes go through the Axis of the Earth, are called Meridians.*

3882. *They all pass through the Poles of the World, and are perpendicular to the Æquator.*

DEFINITION 5.

3883. *The Arch of any Meridian, which is intercepted between the Æquator and a Star, is called the Declination of that Star.*

3884.

Plate 125.

Fig. 2.

Let an Observer be upon the Earth T, who directs his Sight along T A; after a little Time, when the Line T A shall be carried by the Motion of the Earth to T a, if the Spectator directs his Sight along the same Line, the Body A will appear to have been carried through the Arch a A; but when the Line has returned to it's former Situation T A, the Body will seem to have

per-

performed one whole Revolution. But if he directs his Sight along the Axis of the Earth produced, because that's at rest, the Body, which is seen in the Axis, will appear not to have moved; *therefore in the Poles of the World the diurnal Motion is not observed* *. But that Bodies, which are near the Poles, are moved round them is plain; and that the Body by it's diurnal Motion, describes so much a greater Circle round the immoveable Pole, as it is farther distant from it. Therefore *the whole Sphere of the fixed Stars seems to revolve about the Axis of the Earth continued in Antecedentia, in that Time in which the Earth really turns about it's Axis.* Therefore the diurnal Motion is common to all the celestial Bodies, except so far as it is disturbed by the Motions above-mentioned.

3885.

3877.

3886.

The Æquator is equally distant from both Poles, and divides the Heavens into two Hemispheres, whose middle Points are the Poles of the World, which therefore are equally distant from the several Points of the Æquator; therefore *the heavenly Bodies which are in the Æquator by their diurnal Motion seem to describe the Æquator* itself, the greatest Circle of all that can be described by the diurnal Motion; *the other Bodies describe Circles parallel to the Æquator.*

3887.

3888.

The Axis of the Earth is inclined to the Plane of the Ecliptic in an Angle of 66 Deg. 31 Min. * *the Poles of the World therefore are distant from the Poles of the Ecliptic 23 Deg. 29 Min. and the Plane of the Æquator makes an Angle with the Plane of the Ecliptic of 23 Deg. 29 Min.* Both Planes pass through the Center of the Earth, but since this may be looked upon as the Center of the Sphere of the fixed Stars*, it follows, that *the Æquator and the Ecliptic Line are great Circles, which are inclined to each other, and cut one another in two opposite Points in the Beginning of Aries, and the Beginning of Libra, which Points in the Way of the Sun, are determined by these Intersections* *.

3729.

3889.

*3769. 3773.

3890.

*3783. 3888.

When the Sun is in those Points it seems to describe the Æquator by it's diurnal Motion *; when it is carried about in the Ecliptic by it's apparent Motion, it continually recedes more and more from the Æquator, and it's Declination is increased, and it describes less Circles every Day *; till it comes to it's greatest Distance from the Æquator, which is 23 Deg. 29 Min. † then it comes back to the Æquator again, and goes beyond it also 23 Deg. 29 Min. advancing towards the opposite Pole.

3891.

3892.

3888.

† 3889.

3893.

DEFINITION 6.

3894. *Those Circles, described by the Sun in it's diurnal Motion, which are most distant from the Æquator, that is 23 Deg. 29 Min. are called the Tropics.*

3895. *One touches the Ecliptic Line in the first Degree of Cancer, and is called the Tropic of Cancer; the other is called the Tropic of Capricorn, and passes through the first Point of the Sign Capricorn and there touches the Ecliptic Line.*

DEFINITION 7.

3896. *The Pole of the World, which is next to the Tropic of Cancer, is called the Arctic Pole, and also the North Pole; the Opposite is called the Antarctic, and also the South Pole.*

DEFINITION 8.

3897. *The Circles that are described in the diurnal Motion by the Poles of the Ecliptic, that is, by the Points which are distant from the Poles of the World 23 Deg. 29 Min. are called the Polar Circles.*

3898. *The Arctic Polar Circle is that which furrounds the Arctic Pole; the other opposite one borrows it's Name from the Antarctic Pole.*

There remains to be explained the Moon's Motion about it's Axis, whose Effect is that the same Face of the Moon is always turned towards the Earth.

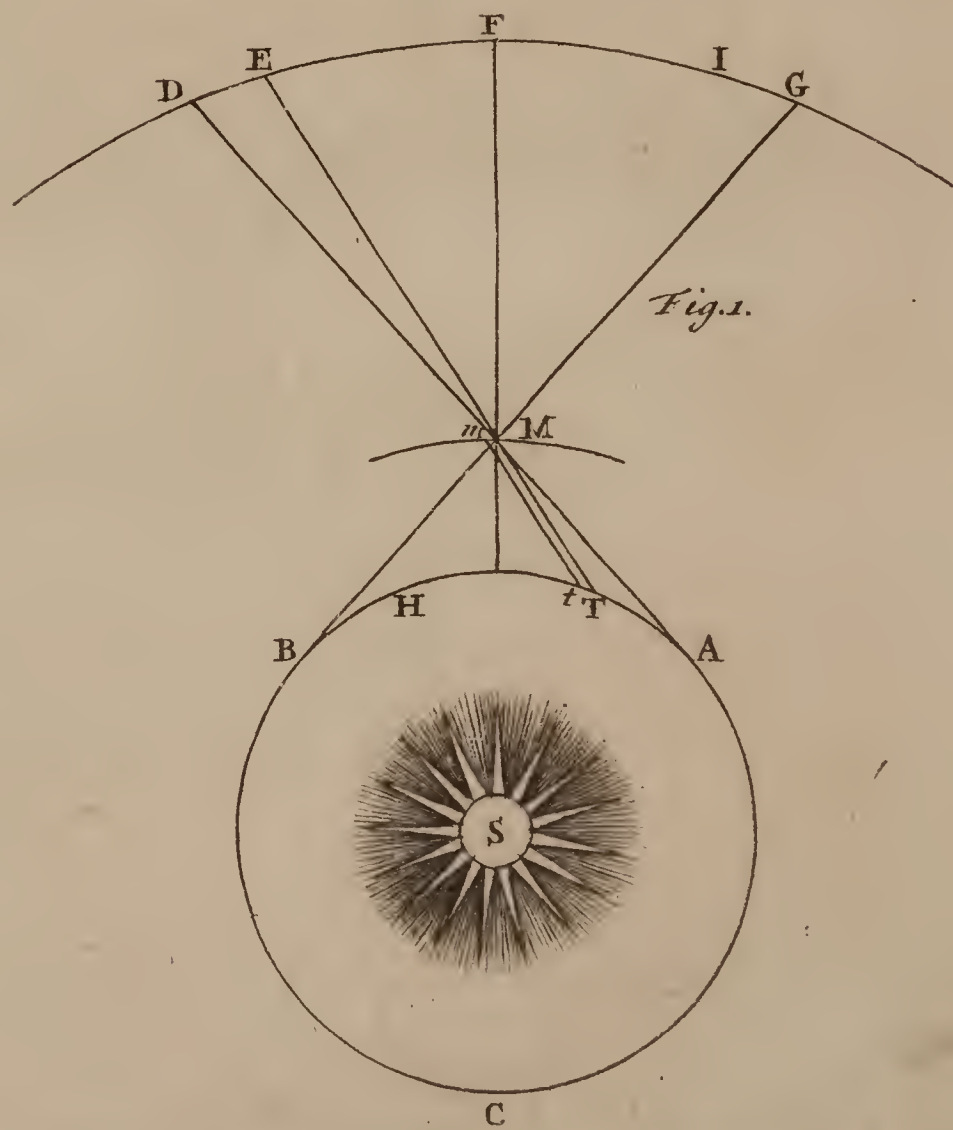
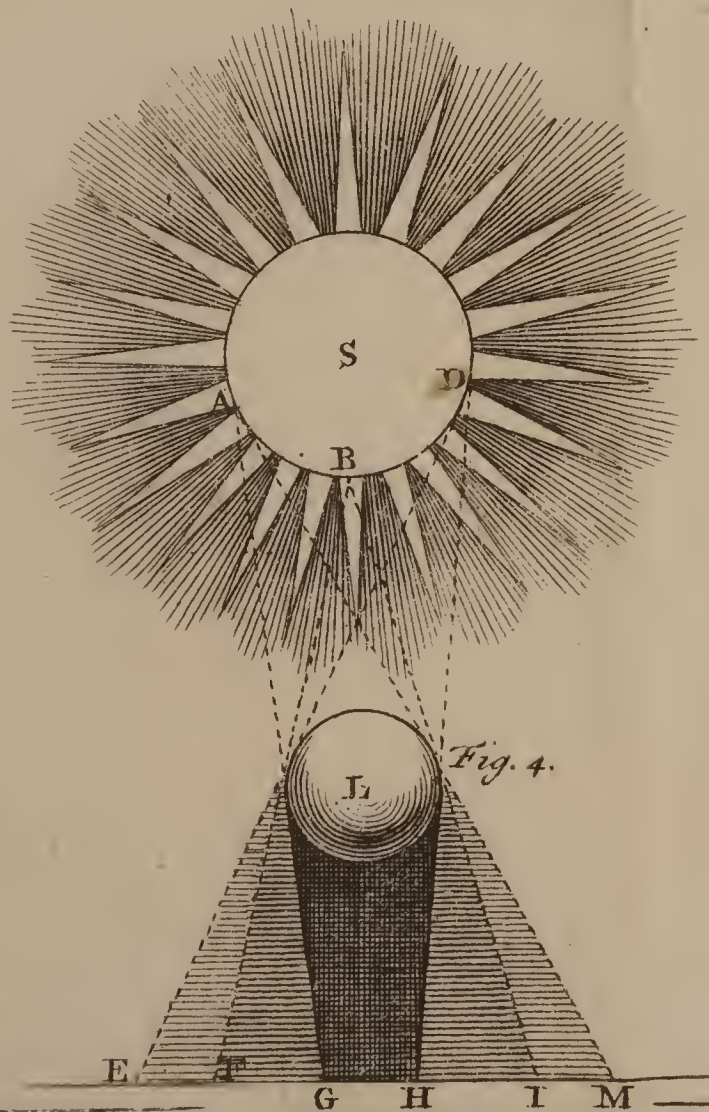
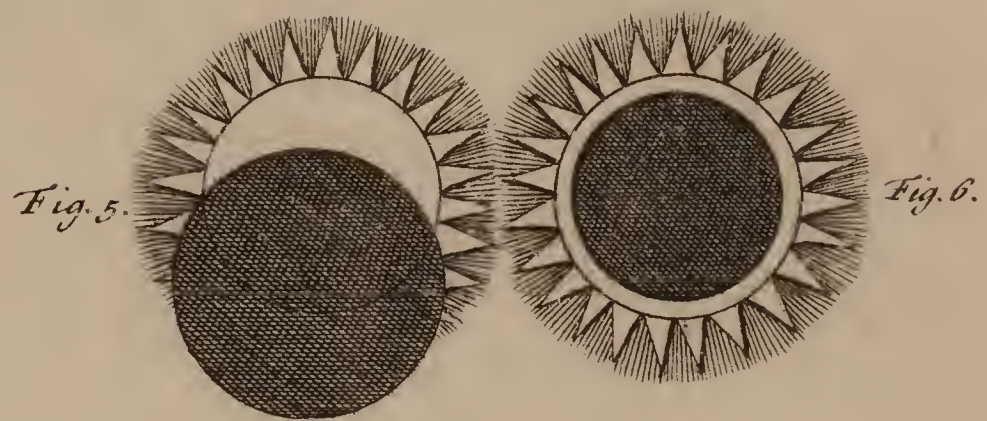
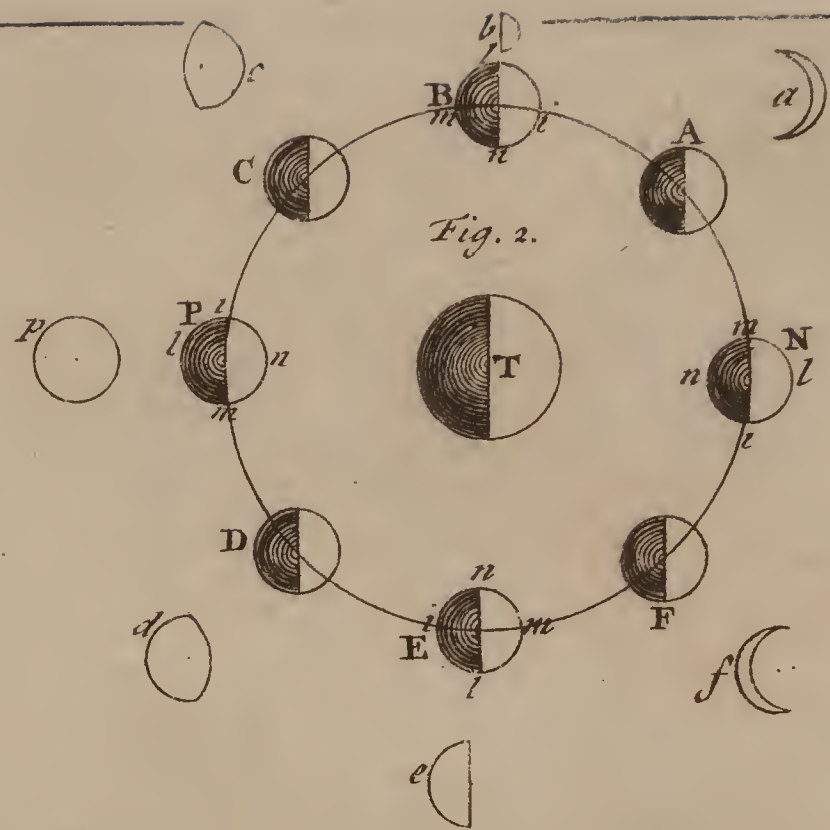
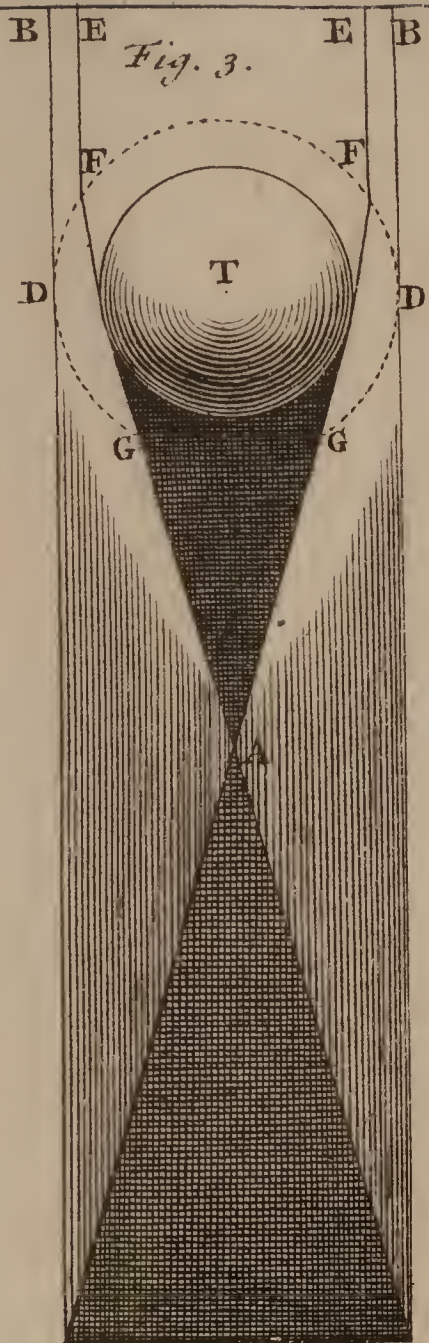
3900. *Let the Moon be at N the Face which is turned to the Earth is mni ; if the Moon did not turn about it's Axis, and all it's Points were carried through parallel Lines, the Line mi would coincide with the Line ln in the Situation of the Moon at B, and the aforesaid Hemisphere mni would be at lmn ; but because, whilst the Moon describes a fourth Part of it's Orbit, it performs likewise $\frac{1}{4}$ of it's Revolution round it's Axis, the Face, which would be at lmn , is now at mni , that is, again turned to the Earth.*

Pl. 124.
Fig. 2.

After the same Manner it is proved, that this same Face mni , when the Moon is at P, is seen by an Observer on the Earth, and that it is turned towards the Earth at E; as also in all other Points of the Moon's Orbit.

That Part of the Moon's Face which, by it's Motion in it's Orbit, is continually turned from the Earth, is turned again towards it by the Moon's Motion round it's Axis.

But



Chap. 8. of Natural Philosophy.

303

But as it's Motion about it's Axis is equal, and it is carried in it's Orbit with an unequal Celerity *; it happens that the Moon * 3739.3740. being in the Perigæum, that is at the least Distance from the Earth, where it is moved very fast in it's Orbit *, it does not entirely * 3739. turn back again towards the Earth by it's Motion round it's Axis, that Part of it's Surface, which it turns from it by it's Motion in it's Orbit; therefore a Part of the Surface of the Moon which was not seen before, appears at it's Side; which becomes again invisible, when the Moon comes to it's apogee.

For that Reason *the Moon seems to be moved with a libratory Motion.* 3902.

There is also another libratory Motion observed in the Moon. 3903.

The Axis of the Moon not perpendicular to the Plane of it's Orbit, but a little inclined to it: The Axis keeps it's Parallelism in it's Motion round the Earth, as has been said of the primary Planets *; therefore it changes it's Situation in Respect of an Observer upon the Earth, to whom sometimes one, sometimes the other Pole of the Moon is visible. 3904. 3721.

C H A P. VIII.

Of the Phænomena which relate to the Surface of the Earth, and it's particular Parts.

WE have explained the cœlestial Phænomena hitherto examined, by considering the Spectator as carried about by those Motions wherewith the Earth is really moved. Now we shall consider him as placed upon the Surface of the Earth, and carried from one Place to another upon it. 3905.

The first Phænomena to be here observed is, that, *by Reason of the Interposition of the Earth, one Half of the Heavens is invisible to the Observer who is placed upon the Surface of the Earth.* 3906.

DEFINITION I.

That Circle in the Heavens, which separates the visible from the invisible Part, when the Rays are not intercepted by the Inequalities of the Earth's Surface, is called the Horizon. 3907.

When the Height, to which the Spectator can be raised above the Surface of the Earth, is very small, compared with the Semi-diameter of the Earth; the Eye of the Spectator may be looked upon as placed in the Surface itself. Let 3908.

3909. Let the Earth be at T, and the Observer at S, and PE *pe* the
 Pl. 125. Sphere of the fixed Stars; if you conceive a Plane at HH to touch
 Fig. 4. the Earth and go through S, it will be the Plane of the Horizon,
 whose Section with the Sphere of the fixed Stars is the Horizon.
 A Plane at *h h*, is conceived to go through the Center of the Earth
 parallel to HH; the Distance *h H* is insensible, by reason of the
 immense Distance of the fixed Stars; therefore the Section of that Plane,
 * 3777. with the Sphere abovementioned, may be taken for the Horizon* HH.

DEFINITION 2.

3910. *The Ascent of the Stars, above the Horizon, is called their Rise.*

DEFINITION 3.

3911. *The Descent, below the Horizon, is called the setting of the Stars.*

DEFINITION 4.

3912. *If we conceive a Line drawn through the Observer and the Center of the Earth, which must necessarily be perpendicular to the Horizon, it will reach the Point Z among the fixed Stars, which is called the Zenith.*

DEFINITION 5.

3913. *The Point N, opposite to it the Nadir.*

DEFINITION 6.

- * 3914. *The Section which a Plane of the Meridian*, that goes through*
 * 3881. *the Observer, makes with the Horizon, is called the Meridian Line; and is directed from North to South.*

DEFINITION 7.

3915. *The Eastern Part of the Heavens is that, towards which we see the cœlestial Bodies rise above the Horizon.*
 3916. *The opposite Part of the Heavens, in which the same Bodies go down below the Horizon, is called the western Part.*
 3917. *These two Points are separated by a Meridian Line, which we conceive to be continued both Ways, in the Plane of the Horizon, quite up to the Heavens.*
 3918. *The East Point is that, in which a Line directed Eastwards, perpendicular to the Meridian Line, and going through the Observer, cuts the Sphere of the fixed Stars.*

DEFINITION 8.

The Point opposite to this is called the West Point.

3919.

DEFINITION 9.

The Amplitude is an Arch of the Horizon, which is contained between the East or West Point, and the Point in which the Star rises or sets, the first is called the rising and the other the setting Amplitude; and each is either northern or southern Amplitude.

3920.

DEFINITION 10.

The Height or Altitude of a Star, above the Horizon, is the Arch of a Circle perpendicular to the Horizon, in whose Center the Spectator is, terminated by the Horizon and the Star.

3921.

When Bodies are remote, the Altitude does not sensibly differ, whether the Spectator be in the Surface of the Earth, or supposed at it's Center; Bodies that are less distant appear higher to a Spectator placed in the Center.

3922.

DEFINITION 11.

The Difference of the Height of a Star, according to the different Position of the Observer, as he is supposed in the Center, or on the Surface of the Earth, is called the Parallax of the Star.

3923.

There is only the Parallax of the Moon, which can be determined by Observations: The Distance of the rest of the Bodies in the planetary System is too great to be compared with the Semidiameter of the Earth; and the Parallax depends upon the Ratio which the Semidiameter of the Earth has to the Distance of a Planet; therefore even the Parallax of Mars, in Opposition with the Sun, is too small for the nicest Observations.

3924.

Where there is a Parallax, it diminishes as a Body ascends above the Horizon, and vanishes in the Zenith.

3926.

*The apparent Height of the Stars is also changed upon another Account, which equally affects all the heavenly Bodies. The Rays are inflected by the Refraction of the Atmosphere, and the Stars appear higher than they are *; yet the higher they are, the less is that * Inflexion †; because the Rays fall less obliquely on the Surface of the Atmosphere. In the Zenith there is no Refraction *; even at the Distance of twenty or thirty Degrees from the Zenith, it is not sensible. **

3927.

3928.

3929.

3856.

† 2809.

3930.

2793.

Since the Stars are raised by the Refraction, they are visible before they come to the Horizon.

3931.

3932. All these Things relate to the Surface of the Earth in general,
 Plate 126. now we must examine the several Parts of it; these are determin-
 Fig. 2. ed by referring to the Earth the Circles which we have before
 3933. considered in the Heavens; *so on the Earth we consider the Æquator,*
the Meridians, the Tropics, and Polar Circles; and these Circles di-
 vide the Surface of the Earth in the same Manner as the Sphere
 of the fixed Stars is divided by the Circles in the Heavens; and
 therefore the Circles in the Heavens, and those upon the Earth,
 do so mutually correspond with each other, that a Line being drawn
 from the Center of the Earth to a Circle in the Heavens, it will
 go through the same Circle in the Earth. If the Poles are Pp ,
 the Æquator will be Ee , the Tropics TT, tt , and the Polar Cir-
 cles AA, aa .

DEFINITION 12.

3934. *The Meridian which goes through a Place is called the Meridian*
of the Place.
 3935. *The Plane of it is perpendicular to the Horizon;* because it goes
 through the Center of the Earth and the Observer.
 3936. *A Meridian Line drawn in any Place, is Part of the Meridian*
 * 3914. *of the Place*.*

DEFINITION 13.

3937. *The Latitude of a Place is it's Distance from the Æquator;* that
 is, the Arch of the Meridian intercepted between that Place and
 the Æquator.

DEFINITION 14.

3938. *Circles parallel to the Æquator, are called Circles of Latitude*
as Bb .
 3939. By determining the Latitude of the Place, we determine the
 Circle of Latitude, which goes through the Place; now to de-
 termine the Situation of several Places, in Respect of each other,
 we must determine Places upon the several Circles, which is done,
 by supposing a Meridian to pass through any remarkable Place,
 which by it's Section determines a Point upon each Circle of La-
 titude, from which the Distances of Places are measured.

DEFINITION 15.

3940. *The Meridian abovementioned, taken at Pleasure, is called the*
first Meridian.

DEFINITION 16.

The Distance of a Place from the first Meridian measured on a Circle of Latitude that goes through a Place is called the Longitude of the Place. 3941.

Astronomers refer every Thing to the Meridian of the Place in which they make their Observations. 3942.

In explaining the Phænomena which relate to the several Parts of the Surface of the Earth, we shall consider the Observer going from the Pole to the Æquator; and first only take Notice of the diurnal Motion. 3943.

*When the Spectator is at S, in the very Pole of the Earth T, the celestial Æquator E e coincides with the Horizon, and the Pole of the World P is the Zenith; in that Case, because the Circles, which are parallel to the Horizon, are also parallel to the Æquator; all the heavenly Bodies appear to be carried by a Motion parallel to the Horizon *, in Circles which are represented by the Lines A a, B b. The heavenly Bodies in the Hemisphere E P e never set, and the others are never visible.* 3944. Plate 125. Fig. 3. 3888.

The Horizon in this Situation is said to be parallel, or this Situation is called a parallel Sphere. 3945.

If an Observer upon the Earth T recedes from the Pole, and is at S, the Horizon is said to be oblique, or the Sphere is oblique; then the Axis P p is inclined to the Horizon h h, so much the more as the Observer is farther from the Pole. 3946. Plate 125. Fig. 4.

DEFINITION 17.

*The Angle which the Axis of the Earth makes with the Horizon, is called the Height of the Pole *.* 3947. *

This Height of the Pole is equal to the Latitude. The Height of the Pole is the Angle P T h, whose Measure is the Arch P h; the Latitude is measured by an Arch, which upon the Earth corresponds to the Arch Z E in the Heavens: But this is equal to the Arch P h; for the Complement of each of them, to a Quarter of a Circle, is the Arch Z P.* 3921. 3948. 3937.

In this Position of the Observer, because the Æquator is inclined to the Horizon, all the heavenly Bodies are carried by the diurnal Motions in Circles inclined to the Horizon, represented by the Lines A a, B b.* 3949. *

Some of the heavenly Bodies rise and set at every Revolution of the Earth; namely those which are between the Parallels to the Æ- 3888. 3950.

quator Bh , and hi ; because all the Parallels between those are cut by the Horizon.

3951. The Planes of the $\text{\AE}quator$ and the Horizon go through the Center of the Earth; therefore these Circles cut one another mutually into two equal Parts, and half of the $\text{\AE}quator$ is above the

3952. Horizon; therefore *the heavenly Bodies, which are in the $\text{\AE}quator$, are above the Horizon during half a Revolution of the Earth about it's*

* 3887. *Axis* *; and on Account of the Equability of the Motion about the Axis are invisible during an equal Time.

3953. *These also rise due East and set due West*, (that is, in the very Points of the East and West;) for the Section of the Planes of the $\text{\AE}quator$ and the Horizon is perpendicular to a Plane perpendicular to both these Planes; and this last Plane is the Plane of the Meridian

* 3881. of the Place *.

3935. Wherefore the abovementioned Section is perpendicular to the

† 3936. Meridian Line †, and consequently goes through the East and West

‡ 3918. 3919. Points ‡.

3954. *Bodies between the $\text{\AE}quator$ and a parallel Bh , which touches the Horizon, as in the Circle Aa , continue longer above than below the Horizon; and this Difference is so much the greater, the more the*

3955. *Circle Aa approaches that Pole, which is above the Horizon. On the contrary, as the Body goes towards the opposite Pole, it's Time of Continuance above the Horizon is the longer.*

3956. *This Inequality of the Time, that a Body is above and below the Horizon encreases as the Height of the Pole does, because of the Diminution of the Angle made with the Horizon by the $\text{\AE}quator$ and it's Parallels.*

3957. *Bodies, whose Distance from the Pole is equal to the Height of it, never set, for such is the Distance of the Circle Bh , which touches the Horizon, but has no Part of it below the Horizon.*

Bodies less distant from the Pole, do not so much as come down to the Horizon.

3958. It appears by the same Reasoning, that *Bodies, whose Distance from the opposite Pole does not exceed the Height of the Pole, never rise above the Horizon, and are always invisible.*

3959. *Bodies, whose Distance EZ from the $\text{\AE}quator$ is equal to the Height of the Pole, go through the Zenith Z , for EZ is equal to the*

* 3948. Latitude of the Place to which the Height of the Pole is equal *.

3960. *When a Spectator S has receded as far as he can from the Pole, Pl. 125. F. 5. he comes to the $\text{\AE}quator$ whose Points are equally distant from each*

* 3933. Pole *; then the Axis Pp is in the Horizon with which the $\text{\AE}qua-$

tor

Chap. 8. *of Natural Philosophy.* 309

tor makes a right Angle*, for which Reason the *Horizon is said* * 3879.
to be right; or this is called a *right Sphere.* 3933.

The Horizon cuts into two equal Parts all the Circles, that are parallel to the Æquator, which are represented by the Lines *Aa, Bb*, therefore, *all the heavenly Bodies at every Revolution of the Earth, rise and set, and are visible and invisible during equal Times.* 3961.

The Æquator itself goes through the Zenith, and therefore all the Bodies that are in it pass through it also. 3962.

If what we have explained concerning the diurnal Motion be applied to the Bodies, of whose other apparent Motions we have spoken before, the Phænomena will be easily determined from the Motions joined together; those that relate to the Sun are more remarkable than the rest, and therefore more particularly to be explained. 3963.

DEFINITION 18.

We call a natural Day the Time elapsed between the Recess of the Sun from the Meridian of a Place, and it's next Return to the same Meridian. 3964.

*This Day differs from the Time of the Revolution of the Earth above it's Axis, which Times would be equal, if the Sun appeared immoveable amongst the fixed Stars: but whilst by the diurnal Motion, in the Time of one Revolution of the Earth about it's Axis, the Sun is carried round from East to West, that is in *Antecedentia* *, it is carried by a contrary Motion in the Ecliptic †, * 3886.
 whereby it comes later to the Meridian. † 3779.*

But as the Sun does not every Day go through an equal Space in the Ecliptic *, all the *natural Days* do not equally exceed the Revolution of the Earth about it's Axis; therefore these Days are * 3966.
unequal to one another. 3967.
 3780.

Natural Days are unequal also upon another Account, namely, by Reason of the Inclination of the Ecliptic in Respect of the Æquator; whence it follows, that the annual Course of the Sun is unequally inclined to the Æquator in different Points; and though the Sun should equally go forward every Day in the Ecliptic, the natural Days would not equally exceed the Time of the Revolution about the Axis; for if the Motion of the Sun be resolved into two Motions *, of which the one is parallel to the Æquator *, * 1155.
 and the other perpendicular to it, the first is only to be considered in determining the Excess abovementioned, and that it is unequal, is plain from the different Inclination abovementioned, as also the different Distance of the Sun from the Pole.

These

3969. These two Causes of Inequality often concur, and often act contrarywise.

3970. Every natural Day is divided into twenty-four equal Parts which are called Hours. Each Hour is divided into sixty Minutes; and each Minute into sixty second Minutes; or Seconds, and so on.

3971. That these Parts of Time vary in different Days, appears plainly
 * 3967. from what has been * said; they are by Astronomers reduced to
 3972. Equality, by considering the Number of Hours in the whole Revolution of the Sun in the Ecliptic, and dividing the whole Time into as many equal Parts as there are Hours, twenty-four of which are taken for one Day.

DEFINITION 19, and 20.

3973. The Time whose Parts are by this Method reduced to Equality, is called the mean Time, and that Reduction is called the *Æquation of Time*.

3974. We always make use of the Days and Hours of the mean Time in determining the Periods of the heavenly Motions.

DEFINITION 21.

3975. The artificial Day is the Time that the Sun stays above the Horizon. We always speak of it, when we mention Day in Opposition to Night.

3976. In determining the Length of artificial Days, we do not attend to the *Æquation of Time*.

3977. The *Crepusculum*, or Twilight always comes before the Sun's Rise, and follows it's setting; this is that dim Light which we commonly call Morning and Evening Twilight.

3978. The Twilight is produced by the Atmosphere which is enlightned by the Sun's Rays, and whose Particles reflect the Light every Way; from whence some Rays come to us, though the Sun be depressed eighteen Degrees below the Horizon.

3979. In the right Sphere, that is to all those that dwell under the

* 3960. *Æquator* *, the Days and Nights are equal to one another all the

† 3961. Year round †, and are of twelve Hours *.

* 3970. In the oblique Sphere the Days are longer or shorter, according to
 3980. the different Distance of the Sun from the *Æquator*, towards either

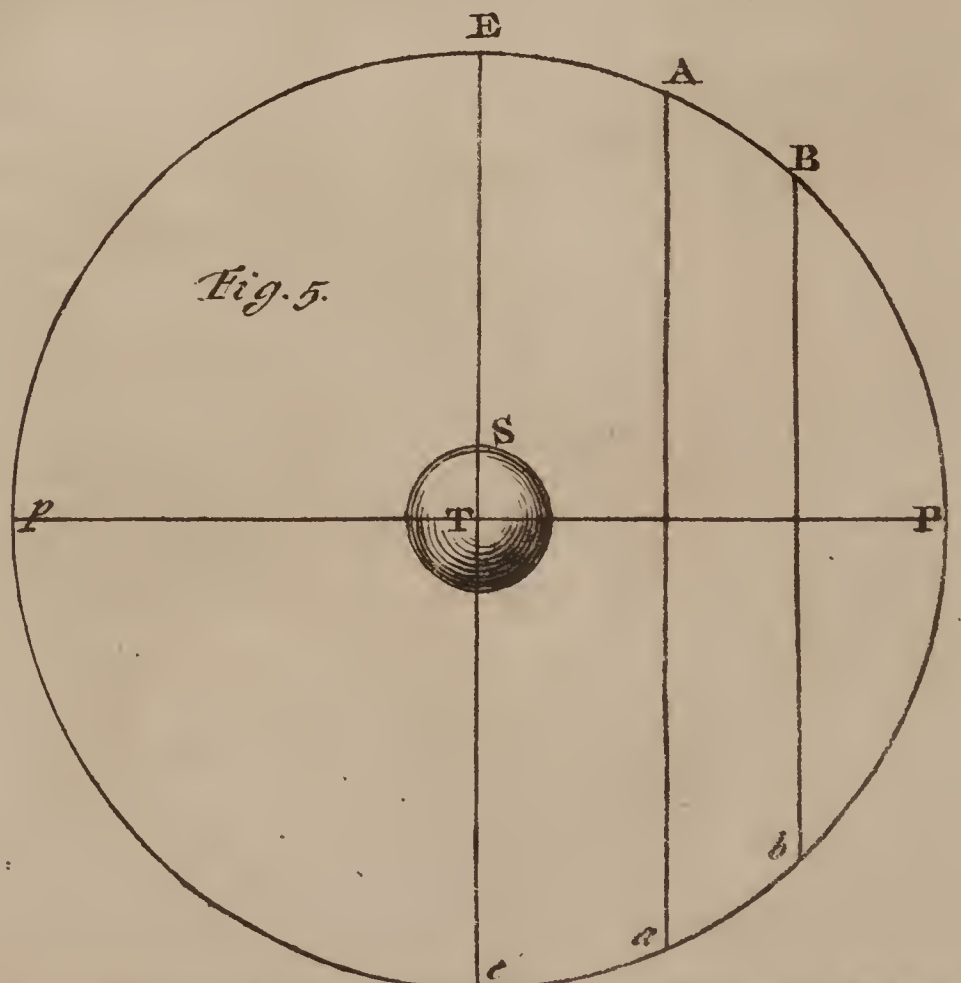
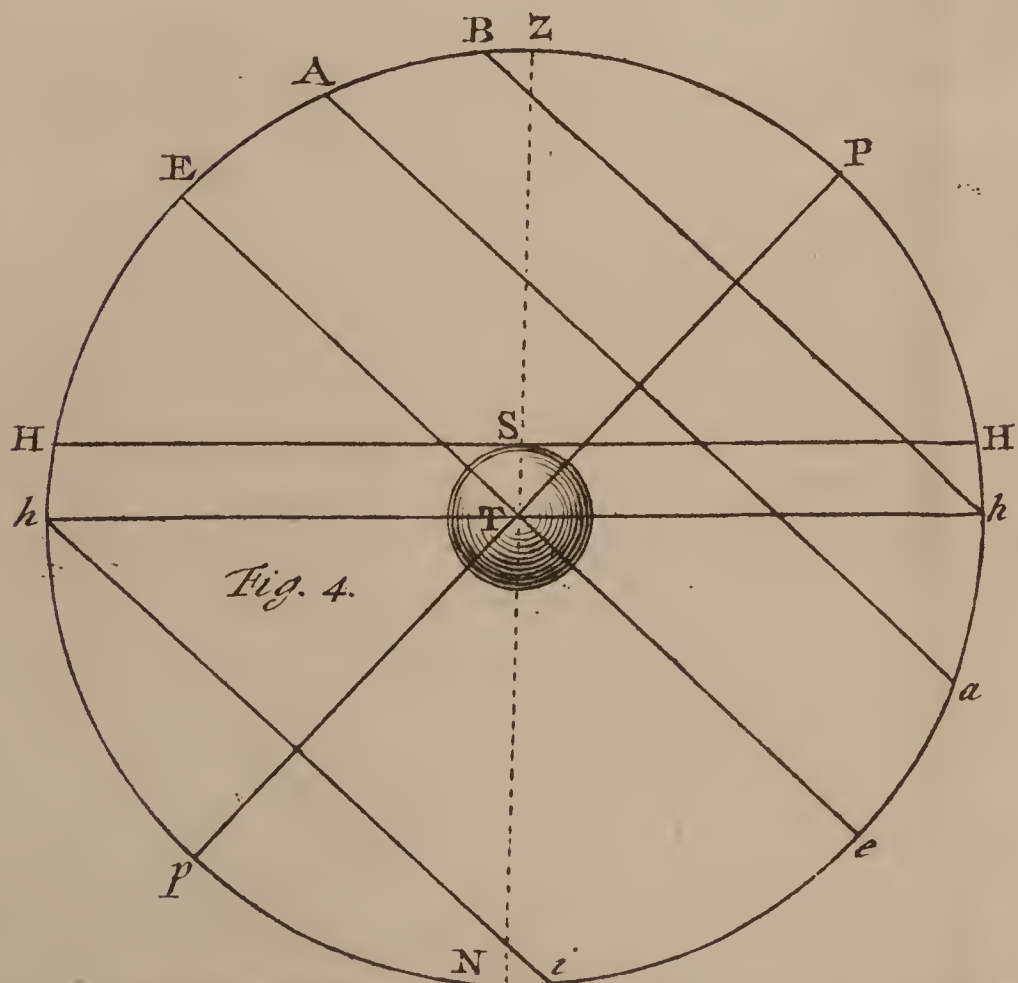
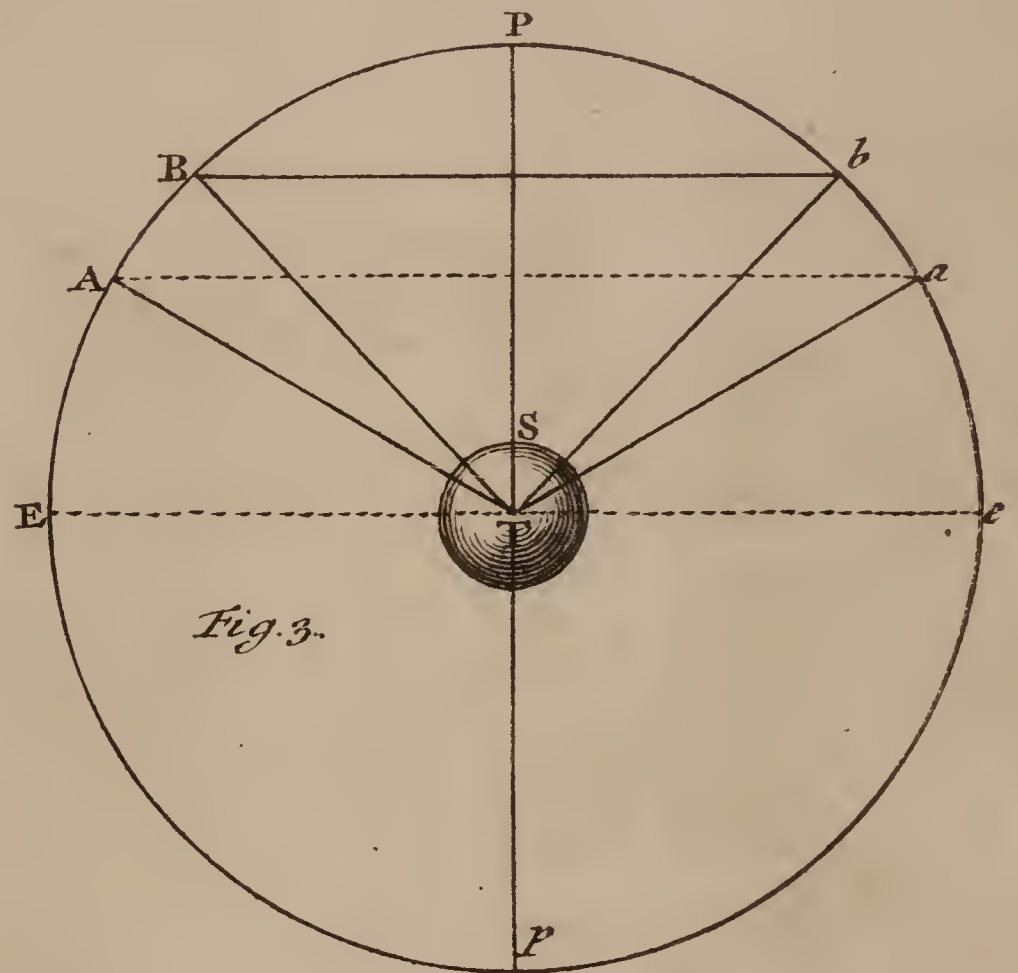
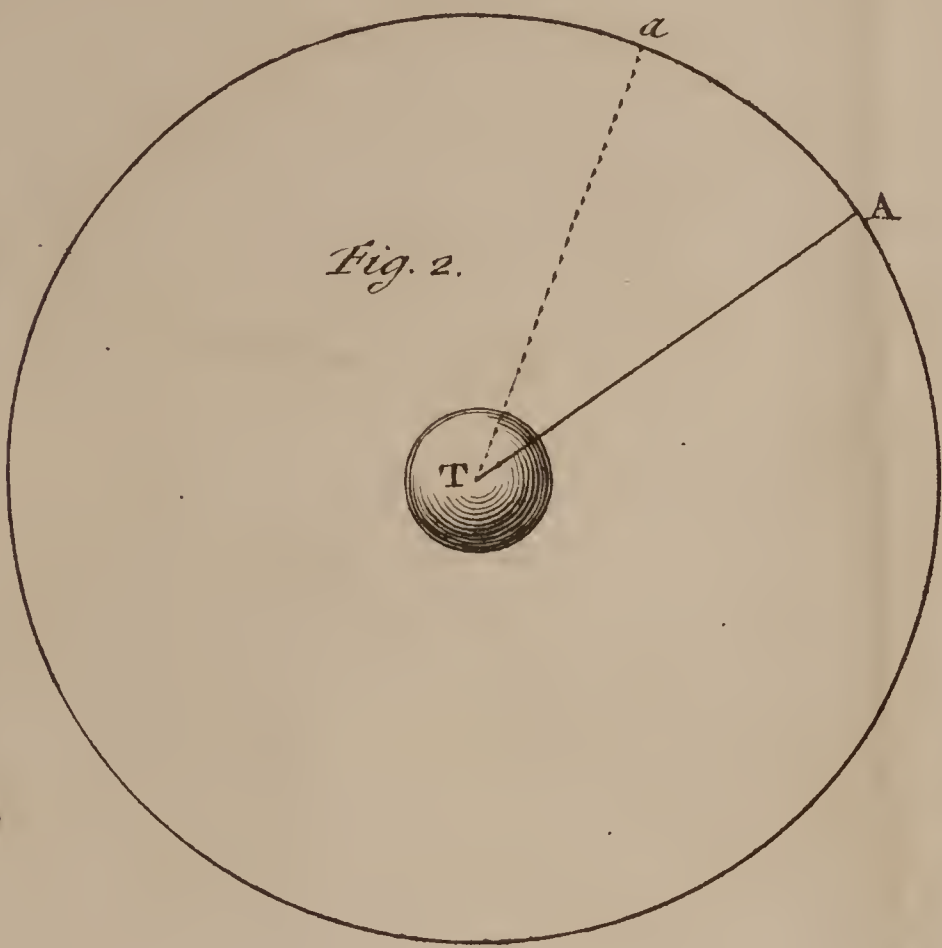
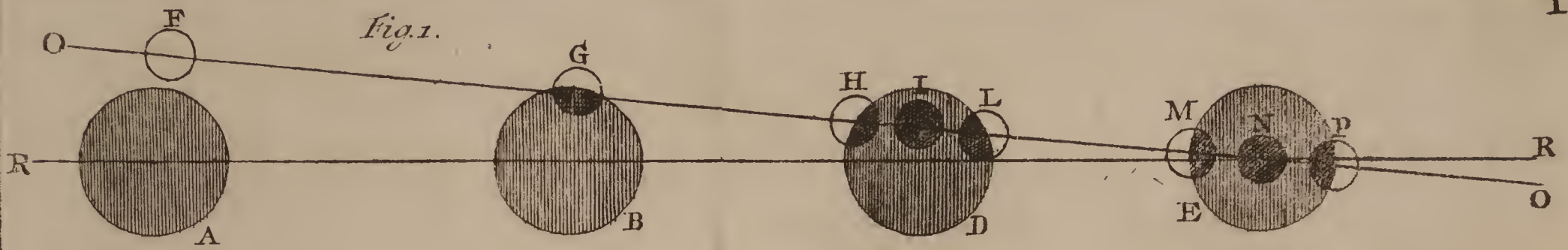
* 3954. 3955. Pole *; for the Sun recedes from the *Æquator* towards the Poles

* 3892. 3893. 23 Deg. 29 Min. *

3981. The Sun is in the *Æquator* about the 10th of March, and the 12th

* 3952. of September, and then the Day is equal to the Night *, which happens all over the Earth, except just at the Poles.

DEFI-



DEFINITION 22.

*Those Points of the Ecliptic in which it is cut by the Æquator * ;* 3982.
*are called the Æquinoctial Points, because the Sun is in those Points, ** 3890.
when the abovementioned Equality of Day and Night happens.

DEFINITION 23.

These Points of the Ecliptic, in which the Tropicks touch that 3983.
*Circle *, are called the Solstitial Points ; because for a few Days, ** 3894.
when the Sun comes to those Points, and goes beyond them, it
does not sensibly change its Declination, and the Length of the
Days does not sensibly vary.

Under the Poles, if there be any Inhabitants there, they can only 3984.
once in a Year see the rising and the setting Sun, and only one Day
with one Night make up their whole Year. The Sun continues above
*the Horizon all the while it goes through one half of the Ecliptic *, ** 3890.
the rest of the Time it is hid under the Horizon. But yet their 3944.
*Day is lengthened upon account of the Refraction * ; and the Twilights* 3985.
*last very long, for they last as long as the Declination of the Sun, ** 3931.
towards the hidden Pole does not exceed 18 Deg. † † 3978.

In respect to the Arctic Pole, in the first six Signs, from Aries to 3986.
Libra, the Sun is above the Horizon ; therefore at the Pole the
*Day exceeds the Night nine natural Days *, besides the Diminution ** 3784
of the Night on Account of the Refraction †. † 3986.

These general Things which relate to the different Positions of the Horizon being explained, some more particular Things are to be examined.

The whole Surface of the Earth is divided into five Zones. The 3987.
first is contained between the two Tropics T T, t t, and called the Tor- 3988.
rid Zone ; there are two Temperate Zones, and two Frigid Zones. Plate 126.

The Northern Temperate Zone is terminated by the Tropic of Fig. 2.
Cancer T T, and the Arctic Polar Circle A A. The Southern Tem- 3989.
perate Zone is contained between t t, the Tropic of Capricorn, and
the Polar Circle a a.

The Frigid Zones are circumscribed by the Polar Circles, and the 3990.
Poles are in the Centers of them.

In the Torrid Zone, twice a Year, the Sun goes through the Zenith 3991.
*at Noon *. For the Elevation of the Pole is less than 23 Deg. ** 3988.
*29 Min. * and the Distance of the Sun from the Æquator towards* 3948.
the Pole, which is above the Horizon, is twice in a Year equal to
*the Height of the Pole *. For which Reason also in the Limits of ** 3892. 3893.
that

3992. that Zone, namely *under the Tropics, the Sun comes to the Zenith*
 * 3892.3893. *only once in a whole Year* *.
 3894.

3993. *In the Temperate and Frigid Zones, the least Height of the Pole*
 * 3892.3990. *exceeds the greatest Distance of the Sun from the Æquator* *; and
 3991. *therefore to their Inhabitants the Sun never goes through the Zenith* †.
 † 3959. *Yet the same Day the Sun rises to a greater Height, the less the Height*
 3994. *of the Pole is; because thereby the Inclination of the Circles of the*
diurnal Motion with the Horizon is less.

3995. *In the Torrid Zone, and in the Temperate Zones, every natural Day*
 * 3950.3955. *the Sun rises and sets* *; for the Distance of the Sun from the Pole al-
 * 3892.3989. *ways exceeds the Height of the Pole* *.

3996. *Yet every where but under the Æquator* * *the Artificial Days are*
 * 3979. *unequal to one another* †; which Inequality is so much the greater,
 † 3954.3956. *the less the Place is distant from a Frigid Zone.*

3997. *But in the Polar Circles, just where the Temperate Zones are*
separated from the Frigid ones, the Height of the Pole is equal to
 * 3894. *the Distance of the Sun from the Pole when it is in the neighbour-*
 3897. *ing Tropic* *; and therefore in that Case, that is, *once a Year, the*
 * 3957. *Sun in its diurnal Motion performs one entire Revolution without go-*
ing down under the Horizon *.

3998. *But every where in a Frozen Zone the Height of the Pole is grea-*
 * 3894. *ter than the least Distance of the Sun from the Pole* *; therefore
 3990. *during some Revolutions of the Earth, the Sun is at a Distance from*
the Pole, which is less than the Pole's Height, and during all that
 * 3957. *Time, it does not set, nor so much as touch the Horizon* *. But
 * 3948. *where the Distance from the Pole, as the Sun recedes from it, does*
 † 3950. *exceed the Height of the Pole or Latitude of the Place* *, the Sun
 3999. *rises or sets every natural Day* †; *then in it's Motion towards the op-*
 * 3958. *posite Pole, it stays in the same Manner, below the Horizon, as was*
 4000. *said of the Motion above the Horizon* *.

These Times, in which the Sun makes intire Revolutions above
 the Horizon, and below it, in it's diurnal Motion are so much
 4001. *the greater, that is, the longest Day and Night last the longer, the*
less the Place in the Frigid Zone is distant from the Pole, till at last,
 * 3984. *at the Pole itself, they take up the Time of the whole Year* *.

4002. *From the same Causes, namely, the Obliquity of the Ecliptic in*
respect of the Æquator, by which are occasioned all the Things
which relate to the Inequality of Days, which is different in dif-
ferent Places; we also deduce the Difference of Seasons, which
succeed one another every Year; I shall speak of them first in respect
to the Frigid and Temperate Zones, and then in respect to the Tor-
rid Zone.

The

The Rays of the Sun communicate Heat to the Air, not only when they come directly from the Sun, but when they are reflected irregularly from Bodies or the Surface of the Earth *. 4003. * 2415.

This Effect is so much greater as the Rays strike the less obliquely against the Surface of the Earth ; and that upon a double Account.

1. If you resolve the Motion of the Light into two Motions *, one * 1155. of which is parallel, and the other perpendicular to the Surface of the Earth ; the Light acts upon Bodies only by the last Motion, which diminishes as the Obliquity increases. 2. There are more Rays acting at one Time upon the same Part of the Surface of the Earth, the more directly they come upon it.

Hence we deduce that *the Causes of Heat increase when the Days increase*, by the Sun coming towards the Pole which is above the Horizon ; because the Sun does daily ascend to a greater Height ; so that to the diminished Obliquity is added the longer Continuance of the Sun above the Horizon, both which concur to the increasing of the Heat ; the Nights also are diminished as the Days increase, and the Heat that is produced by Day has less Time to decrease in. 4004.

In the Northern Zones, as follows from this, the Cause of the Heat is the greatest of all, when the Sun comes to the Tropic of Cancer *. Yet the Heat is not always the greatest where the Cause of * 3896. Heat is the greatest ; for the Heat increases as long as that which 4006. is acquired by Day is not wholly destroyed by Night ; for though the daily Augmentations be diminished, as long as there is an Augmentation the Heat increases. *The most intense Cold is not upon the shortest Day*, in which the Obliquity of the Sun's Rays is the greatest, and the Absence of the Sun the longest ; but the Cold increases, as long as the Diminution of the Heat does last ; concerning which one may reason in the same Manner as concerning the Increase of Heat. 4007.

The Year is divided into four Seasons ; the hottest is called the Summer ; the coldest the Winter ; the temperate Season that follows the Winter, Spring ; and the Autumn comes between Summer and Winter. 4008.

*In the Northern Regions, in the Beginning of Spring, the Sun appears to be in the Beginning of Aries ; in the Beginning of Summer the Sun comes to the Tropic of Cancer. When the Sun enters Libra, the Autumn begins : In the Beginning of Winter the Sun performs it's diurnal Motion in the Tropic of Capricorn ; all which may be easily deduced from what has been explained *. 4009. * 4006, 4007.*

4010. *In the Southern Regions the Summer happens in the the Time of Winter abovementioned, and they have their Spring whilst the former have their Autumn; and so of the other Seasons.*

The general Causes, upon which the Division abovementioned depends, are often disturbed by Causes relating to particular Places: especially in the Torrid Zone, of which we said we must treat separately. In most Places of this Zone there are only two Seasons observed (viz.) Summer and Winter, which are chiefly distinguished by dry and wet Weather.

4012. *When the Sun comes to the Zenith of any Place, there are almost continual Rains, upon which Account the Heat is diminished,*
 4013. *which Time is referred to, or called Winter. As the Sun recedes, the Rains diminish, the Heat is increased, and that Time is referred to Summer.*

4014. *In the Middle of the Torrid Zone, there are two Summers, and as*
 * 3991. *many Winters; because the Sun comes up twice to the Zenith *.*

4015. *Towards the Sides of this Zone, though the Sun comes twice to the Zenith; yet since there is but a small Time between it's coming to it the first and second Time, both the Winters are confounded into one, wherefore only two Seasons in a Year are observed there.*

C H A P. IX.

Concerning the Phænomena arising from the Motion of the Axis of the Earth.

* 4016. *WE have said that the Axis of the Earth is carried by a*
 * 3721. *parallel Motion *; we have not considered a small Motion, whereby it is really moved, of which we shall now speak.*

4017. *The Axis of the Earth, keeping the Inclination of 66 Deg. 31 Min. to the Plane of the Ecliptic, revolves in Antecedentia, that is, is successively carried towards all Parts; and it's Extremities, (viz.)*
 4018. *the Poles of the World describe Circles round the Poles of the Ecliptic, from East to West. And this Revolution is performed in the Time of about 26000 Years, which Period is called the Great Year.*

4019. *Because the Earth is looked upon as immoveable by it's Inhabitants, this Motion is referred to the heavenly Bodies, as has been said of the other Motions. Therefore whilst the Poles of the World are moved about the Poles of the Ecliptic in Antecedentia,*
 and

and pass successively through all the Points that are 23 Deg. 29 Min. distant from these Poles, these Points themselves, or rather the fixed Stars that are in them, come towards the Poles of the World successively, and seem to be carried in *Consequentia*, and to describe Circles which are really described by the Poles of the World about the Poles of the Ecliptic, which, being placed in Centers, alone are at rest. For together with the Stars abovementioned the rest of the Stars (because they keep the same Situation in respect to one another) * do also appear to be moved.

* 3689.
4020.

Therefore *the whole Sphere of the fixed Stars seems to move, in Consequentia, about an Axis passing through the Poles of the Ecliptic; and each Star apparently describes a Circle parallel to the Ecliptic; by which Motion the Latitude of the Stars is not changed.*

The Plane of the *Æquator* makes a right Angle with the Axis of the Earth; therefore, by the aforesaid Motion of its Axis, the Section of the Plane of the *Æquator*, with the Plane of the Ecliptic, is moved round; wherefore *the first Points of Aries and Libra**, which are always opposite, move through the whole Ecliptic Line in the Space of about 25920 Years in *Antecedentia*: Yet they are looked upon as immoveable by the Inhabitants of the Earth, who imagine that the fixed Stars themselves are moved in *Consequentia* *.

4021.
* 3890.

This Translation of the first Point of Aries and Libra, which is called the *Præcession of Æquinoxes*, is the Reason why the Sun, when it has receded from one of these Points, returns to it again before it has performed one intire Revolution in the ecliptic Line: But as the *Æquinoxes* determine the Vulgar or Ecliptic Year, the periodical Time of the Earth exceeds that Year *.

* 4020.
4022.*
* 3729.

C H A P. X.

Concerning the fixed Stars.

WE have said that the fixed Stars are lucid Bodies, removed so far off, that their Distances can be compared with no Distances in the planetary System. For *Astronomers have not been able, by their nicest Observations, to observe the Poles of the World carried out of their Place in the annual Motion of the Earth**, although they describe Circles in the Heavens which are equal to the Earth's Orbit *.

4023.

4024.

* 2654.

* 3721.

DEFINITION I.

4025. This Motion of the Pole is called the *annual Parallax*.

4026. That the fixed Stars are at an immense Distance, it is also proved
4027. by Observations with the Help of Telescopes, *if any fixed Star*, even the lucid and conspicuous, *be beheld with a Telescope*, through which the Diameter of the Sun would appear equal to the Diameter of the Earth's annual Orbit, *it will appear to be a lucid Point, without any sensible Magnitude*; for all the fixed Stars appear less when they are seen through Telescopes, than they do to the naked Eye; for 'tis only their Twinkling which makes them appear to have any sensible Magnitude.

4028. That the Stars may be distinguished, they are referred to various Figures, which are imagined in the Heavens, and are called *Constellations*.

4029. Twelve Constellations are imagined to be in the Zodiac, which are called the *Signs of the Zodiac*; they receive their Names from the Animals or Things which they represent: *Aries, Taurus, Gemini, Cancer, Leo, Virgo, Libra, Scorpius, Sagittarius, Capricornus, Aquarius, Pisces*.

4030. These Signs have given their Names to twelve Parts of the *Ecliptic*,
* 3783. of which we have spoken before *.

In the Time of *Hipparchus*, the Sections of the *Ecliptic* and *Æquator* were between the Constellations of *Pisces* and *Aries*, and *Virgo* and *Libra*, and the Constellations gave their Names to those Parts of the *Ecliptic*, which passed through each Constellation, and the Parts of the *Ecliptic* supposing the Beginning of *Aries* and *Libra*, in the Intersections of the *Æquator* and the *Ecliptic*, have kept the Names which they had at that Time, though these Intersections be carried from their old Places *; whence the Sun is said to be in *Taurus*, when it moves amongst the Stars of the Constellation *Aries*.

4032. The Zodaic separates the North Part of the Heavens from the South Part.

4033. In the Northern Region are the following Constellations: the lesser Bear, the greater Bear, the Dragon, Cepheus, the Hounds, Bootes, the Northern Crown, Hercules, the Harp, the Swan, the Lizzard, Cassiopeia, Camelopardus, Perseus, Andromeda, the Triangle, the lesser Triangle, the Fly, Auriga, Pegasus, or the Flying-Horse, Equuleus, the Dolphin, the Fox, the Goose, the Arrow, the Eagle, Antinous, Sobiesky's Shield, Serpentarius, the Serpent, Mount Mænalus, Berenice's Hair, the lesser Lion, the Lynx. In

Chap. 10. of Natural Philosophy.

317

*In the Southern Region of the Heavens, are the following Constellations, many of which are invisible to us * : namely the Whale, the River Eridanus, the Hair, Orion, the great Dog, Rhinoceros, the lesser Dog, the Ship Argo, Hydra, the Sextant of Urania, the Cup, the Crow, the Centaur, the Wolf, the Altar, the Southern Crown, the Southern Fish, the Phœnix, the Crane, the Indian, the Peacock, the Bird of Paradise, the Southern Triangle, the Cross, the Fly, the Chamælean King, Charles's Oak, the flying Fish, the Toucan or American Goose, Hydrus, or the Water Serpent, Xiphias, or the Sword Fish.*

4034.
3958.

DEFINITION 2.

The Stars, which are between the Constellations, are called unformed Stars.

4035.

The Stars are not equally lucid, and they are referred by Astronomers to six Classes, the most lucid are called Stars of the first Magnitude; others are said to be Stars of the second Magnitude, others of the third, &c. to the sixth Magnitude.

4036.

Some are not referred even to this last Class, and are called Nebulous Stars.

4037.

There is also a certain Zone or Belt observed in the Heavens, which is not every where of the same Breadth, and goes round the whole Heavens, and in some Places is separated, so as to become double. From its Colour it is called the milky Way. It is plain from Observations by the Telescope, that this Way is an Assemblage of innumerable fixed Stars, which cannot be seen by the naked Eye, either because they are less than the other Stars, or more distant.

4038.

Towards the Antarctic Pole there are two Nubeculæ, of the same Colour as the Milky Way, which are also Heaps of small Stars, and cannot be seen without a Telescope. Besides the Stars, which are observed in these Nubeculæ, and in the Milky Way, to whatsoever Parts of the Heavens you point the Telescope, you may discover small Stars in a great Number which are not visible to the naked Eye. Very often an Heap of Stars appears to the naked Eye to be but one Star.

4039.

4040.

4041.

Amongst the Stars, some are visible and invisible by Fits, and observe regular Periods; others are successively sometimes more lucid, sometimes of a duller Light, and to be seen only by the Help of a Telescope, and that at certain Times.

4042.

Yet they are not equally bright at every Period. Sometimes Stars have appeared suddenly, exceeding the brightest in Light, which afterwards,

4043.

terwards, successively decreasing, have vanished in a short Time, and still remain invisible.

4044. Besides the Stars, *we observe in the Heavens several whitish Spots, which are in some Measure lucid and invisible to the naked Eye; their Light is referred to the Stars which are in them, or they are looked upon as nebulous Stars.*

What these Spots are cannot be determined; perhaps they are a Congeries of Stars, which have the same Relation to the Telescopick Stars, as those which form the Milky Way have to those which are seen by the naked Eye.



Mathematical Elements

OF

NATURAL PHILOSOPHY

CONFIRM'D BY

EXPERIMENTS.

BOOK VI.

PART II. The Physical Causes of the Celestial Motions.

CHAP. XI.

Concerning universal Gravity.

HAVING explained the Motions of the heavenly Bodies, 4045.
and the Phænomena arising from them, we must now examine
by what Laws these Motions are performed.

We have before laid down the Laws according to which the 4046.
Motions of Bodies are directed *. If we add one to these, we * 355. 356.
shall see the whole Contrivance by which that vast Machine, the 361.
Planetary System, is governed.

The Law to be added to the rest, is this. *All Bodies are mu-* 4047.
tually heavy (or gravitate) towards each other.

This Gravity is proportional to the Quantity of Matter. 4048.

At unequal Distances it is inversely as the Square of the Distance. 4049.

That

4050. That is, all Bodies mutually attract or tend towards each other, with the Force which belongs to each Particle of Matter acting upon each Particle; and the Force, with which a Body acts upon others, is compounded of the joint Forces of all the Particles of which the Body consists; so this Force increases in the Proportion of the Quantity of Matter, and is unchangeable in every Particle; it is always the same at the same Distance; but the Distance increasing, the Force decreases as the Square of the Distance increases.

4051. *We call this Force Gravity, when we consider a Body which of itself tends towards another; because this Force is called by this Name*
 * 148. *near the Earth's Surface *.*

4052. *But when we consider a Body, towards which another tends, we call the Force Attraction.* We mean the same Effect by these Names, and nothing but the Effect; for since all Gravity is reciprocal *, it
 * 361. is the same to say, all Bodies gravitate mutually towards one another, as that Bodies mutually attract one another, or mutually tend towards each other.

4053. We look upon this Effect as a Law of Nature *; because it is constant, and its Cause is unknown to us, and cannot be deduced from Laws that are known, as we shall shew by and by. Now that there is such a Gravity, is to be proved from Phænomena.

4054. *All the primary Planets are kept in their Orbits by Forces, which*
 * 586. *tend towards the Center of the Sun**; therefore there is a Force by
 3712. which the Planets are carried towards the Sun, and whereby the
 * 361. Sun tends reciprocally towards each of them *: That is, *the Sun*
 365. *and Planets gravitate mutually towards each other.*

4055. After the same Manner it is plain, that *the Satellites of Jupiter and Jupiter gravitate towards each other; as also that the Satellites of Saturn gravitate towards their primary Planet, and that towards them *.*

* 586. *The Moon and the Earth also gravitate towards each other.*

3739. 365. 4056. *All the secondary Planets gravitate towards the Sun.* For they
 * 588. 3739. are all carried by a regular Motion about their primary Planets, as
 365. if the primary Planets were at rest; whence it is plain, that they are carried about by the common Motion with the primary Planets; that is, that the same Force, by which the primary Planets are every Moment carried towards the Sun, acts upon *the secondary ones*, and that they are carried towards the Sun with the same *Celerity as the primary Planets.*

4058.

Even the Irregularities of the secondary Planets, which are so small, as only to be sensible with respect to the Moon, confirm this Gravity of the secondary Planets towards the Sun; for we shall shew hereafter, that all the Irregularities are caused by the Change of the Moon's Gravity towards the Sun, at a different Distance; and because the Lines, in which the Earth and Moon tend towards the Sun, are not altogether parallel.

4059.

From the Gravity of the secondary Planets towards the Sun, it follows, that *the Sun gravitates towards them* *.

4060.

* 361. 365.

In respect of the Gravitation of the primary Planets towards one another, Astronomers have observed that *Saturn* changes its Way a little when it is nearest to *Jupiter*, which is far the greatest of all the Planets; so that it is plain from immediate Observations, that *Jupiter and Saturn gravitate towards each other*.

4061.

4062.

Saturn also in this Case, as *Flamsteed* has observed, disturbs the Motion of *the Satellites of Jupiter*, attracting them a little to itself; which proves that these Satellites *gravitate towards Saturn, and Saturn towards them*.

4063.

4064.

4065.

Having compared together all that has been said from N^o 4054 to 4062. it follows, that the seventeen Bodies, of which the planetary System is made up, mutually gravitate towards each other, although no immediate Observations can be made concerning the Gravitation of each particular one towards the rest *.

* 11.

The second Part of the Law is *, that Gravity is proportional to the Quantity of Matter; that is, that all the Particles of Matter gravitate towards each other; and therefore that the Law of Gravity is universal, and that every Body acts upon all other Bodies; which is deduced from Phænomena.

4066.

4048.

The Forces of Gravity are as the Actions produced in the same Time *, and those Actions, if the Translations are equal, are to one another, as the Quantities of Matter in the Bodies transferred*; therefore since unequal Bodies at the same distance from the attracting Body, move equally swift by Gravity *, it is evident, that the Forces of Gravity are proportional to the Quantity of Matter *.

4067.

126.

* 131. 132.

4057.

We find the same in all Bodies *near the Earth's Surface*, which have a Gravitation towards the Earth, proportional to their Quantity of Matter *.

4068.

* 156.

But *the mutual Gravity of all these Bodies towards one another is not sensible*; because it is exceeding small in respect to their Gravity towards the Earth; and therefore cannot disturb their Motion arising

from their Gravity towards the Earth; at least, so as to make any sensible Change in the Direction of their Motions.

4069. We shall presently shew, by another Method, that this universal Gravity of all the Particles of Matter, whereby they act upon

* 4072. 4074. one another, may be proved from Phænomena *.

4070. The third Part of the Law, which we examine, is, that Gravity decreases when the Distance increases, and is inversely as the Square of the Distances, which also follows from Phænomena.

4071. Bodies, upon which Gravity acts according to their Quantity of Matter, as in our System, are moved with an equal Celerity in the same Circumstances, as we said before; so that it is no Matter, whether the Bodies are greater or less; and they are moved as if they were equal: But in this Case, if the Force towards a Point decreases in an inverse Ratio of the Square of the Distance from that Point, and the Bodies move at various Distances from it, and are kept in Circles by that Force; the Squares of the Periodical Times will be to one another, as the Cubes of the Distances *. Which is demonstrated by Geometers to obtain (in respect of the mean Distances) in Elliptic Lines, whose Forces are directed to their *Foci* *. But this is the Case in Bodies which revolve about the Sun, *Saturn* and *Jupiter* *; whence it follows, that the Force of Gravity, receding from the Centers of these Bodies, decreases in an inverse Ratio of the Squares of the Distances.

* 621. 623.

* 627.

* 3747.

4072.

By this Reasoning supposing Gravity proportional to the Quantity of Matter, we demonstrate, that it decreases in an inverse Ratio of the Square of the Distance. And by the same Reasoning, supposing the Diminution of Gravity to be in this Proportion it follows, that Gravity is proportional to the Quantity of Matter as is very evident.

4073.

But we prove by another Argument, that the Diminution of Gravity so often mentioned, is in an inverse Ratio of the Square of the Distance; so that there can remain no Doubt concerning the two Laws of Gravity, which we now treat of.

4074.

* 3696.

† 3697. 4054.

* 637.

4075.

The Planets are moved in Orbits at rest *; and are kept in them by Forces, which are directed to an excentric Point †; but it is plain, that this would not obtain, if the central Force did not increase in an inverse Ratio of the Square of the Distance *.

It follows from the same Reasoning, that receding from the Center of the Earth, Gravity decreases according to the same Law. For the Moon is retained in it's Orbit by a Force which tends towards the Center of the Earth, that is to an excentric Point *: and

* 586. 3739.
3749.

and though the Line of the Apfides is not carried by a parallel Motion, it's Agitation is fo small, if we confider every Revolution, that it may be looked upon here as quiefcent : In the 16th Chapter we fhall compute the Force which keeps the Moon in its Orbit fo agitated, and we fhall find the Diminution of the Force of Gravity, in refpect of the Moon, to differ very little from an inverfe Ratio of the Square of the Diftance, and we fhall fhew hereafter, that this Difference depends upon the Action of the Sun.

And no Doubt will remain concerning this Diminution, if we confider, *that the Moon is kept in it's Orbit by that very Force, wherewith Bodies are carried towards the Earth, near the Earth's Surface* ; which is diminished according to the Law of Diminution fo often mentioned.

4076.

The mean Diftance of the Moon is $60\frac{1}{2}$ Semidiameters of the Earth : that is 60, 50. Let us fuppofe it to be 60, 522 ; which Correction is fmall, if we confider alfo that this that we fuppofe is a Mean between feveral mean Diftances determined by different Aftronomers. We have before fhewn, that a Diameter of the Earth contains 3389940 *Rbynland* Perches* ; whence knowing the periodical Time ‡, of the Moon, we eafily difcover that the Moon, ‡ in one Minute of Time, goes through 196594 *Rbynland* Perches of her Orbit. This Arc is not the hundredth Part of one Degree, and may be looked upon as it's Subtenfe ; therefore the Diameter of it's Orbit is to this Arc ; as the Arc itfelf is to it's verfed Sine, which is difcovered to be of 15,6982 *Rbynland* Feet, and it is the Space which the Moon and Earth would go through in one Minute, coming to one another by their mutual Attraction.

4077.

3750.

3743.

But as we have obferved, the Gravity of the Moon to the Earth is changed by the Sun's Action ; and as we fhall fhew in the 16th Chapter, the Effect of the whole Action coincides with the Diminution of the Gravity, which is to the Gravity itfelf, as 1 to 180,66 ; wherefore the Space 15,6982 muft be increafed in that Proportion, that the Diminution from the Action of the Sun may be taken away, and then it will be 15,7851 Feet.

The Space gone through by a Body which Gravity caufes to come towards another, depends upon the Force by which it is attracted by it, all whole fingle Particles of Matter attract it* ; therefore the Spaces run through by the Moon and the Earth, in their Access, are inverfely as the Quantity of Matter in them. Therefore as the Quantity of Matter in both the Bodies of the Moon and Earth together, is to the Quantity of Matter in the Earth ; fo is the

4078.

4066.

Space run through by both in their mutual Access, to the Way run through by the Moon alone. But the Quantities of Matter in the Moon and Earth, as we shall shew in the last Chapter, are to one another as 1 and 39,31., and 40,31, is to 39,31., as 15,7851. to 15,3935., the Space run through by the Moon; which therefore any Body would go through toward the Earth in one Minute, setting out at the Distance of the Moon*.

* 4067.

4079.

This Force increasing in the inverse Ratio of the Squares of the Distances, the Space run through at the same Time at the Distance of one Semidiameter of the Earth, that is in it's Surface, will be of $60,522 \times 60,522 \times 15,3935$ Feet; but because in every Motion equably accelerated, as here, (for we consider the Force at the Distance of the Surface of the Earth from it's Center) the Squares of the Times are, as the Spaces run through in their Fall*, dividing that Number by 60×60 , that is 3600, we have the Space run through by a Body in a second Minute near the Earth, by the Force with which the Moon is retained in it's Orbit, which is found to be 15,6625 *Rbynland* Feet.

* 374.

4080.

* 147.

† 415.

Now if we examine the Gravity which we experience every Day in all Bodies on the Surface of the Earth*; from what has been demonstrated concerning the Motion of Pendulums†, and by very accurate Experiments made at *Paris* and in *Lapland* upon Pendulums, it appears, that Bodies under the Poles in one Second fall 15,6743 *Rbynland* Feet; and under the *Æquator* 15,5966 Feet. But Bodies under the *Æquator* are directly pushed upwards by the centrifugal Force; and as every Point of the *Æquator* in one Minute goes through 1487,44 Feet, as is certain from the known Time of the Revolution of the Earth, and the known Diameter of the *Æquator*, which we determine in the 17th Chapter, as also since the versed Sine of that Arc is of 0,0542 Feet, this Sine shews the Space, which Bodies ascending by the centrifugal Force, in one Second would go through if they were not hindered by Gravity. Gravity is diminished by the Action of that centrifugal Force, which being set aside, Bodies under the *Æquator* would in one Second run through 15,6508 Feet by Gravity. Therefore Bodies by Gravity which is a Mean between this Gravity and that at the Pole, will go through 15,6625 in *Rbynland* Feet in one Second. And this Gravity is the very same Force which retains the Moon in it's Orbit.

4081.

We have considered the Centers of the Bodies in examining the Law of the Diminution of Gravity, although Gravity belongs to all the

the Particles of Bodies; because it is plain by the Mathematical Demonstration, which we shall give in the next Scholium, that *the Action of a spherical Body (in which, in every Part, the Particles, that are equally distant from the Center, are homogeneous, and which is made up of Particles, towards which there is a Gravity that decreases, receding from each of them in an inverse Ratio of the Square of the Distance) is directed towards the Center of the Body, and receding from it, is diminished in the same inverse Ratio of the Square of the Distance*: So that such a Body acts, as if all the Matter, of which it consists, was collected in it's Center. Whence we deduce the following Conclusions.

4082.

That on the Surfaces of Bodies, in which the Matter is homogeneous at equal Distances from the Center, the Gravity is directly as the Quantity of Matter in the Bodies *, and inversely as the Squares of the Diameter †; for in these Bodies the Distances from the Center are as the Diameters.

4083.

* 4048.

† 4049.

That on the Surfaces of Bodies that are spherical, homogeneous, and equal, the Gravities are, as the Densities of the Bodies; for the Distances from the Center are equal; in which Case the Forces of Gravity are as the Quantities of Matter *; which in equal Bodies, are as their Densities †.

4084.

* 4048.

† 1463.

That on the Surfaces of the Bodies, that are spherical, unequal, homogeneous, and equally dense, the Gravities are inversely as the Squares of the Diameters, because the Distances from the Center are in the Ratio of those Diameters *, the Gravities also are directly as the Cubes of their Diameters †; for the Quantities of Matter in Spheres are in that Ratio *: And the Ratio compounded of that direct Ratio of the Cubes of the Diameters, and the inverse Ratio of the Squares, is the direct Ratio of the Diameters themselves.

4085.

* 4049.

† 4048.

* 18. El.

Therefore if both the Densities and the Diameters differ, the Gravities on the Surface will be in a Ratio compounded of the Densities * and the Diameters †. Therefore dividing the Gravity on the Surface, by the Diameter, you will have the Density; which consequently is in a direct Ratio of the Gravity on the Surface, and an Inverse Ratio of the Diameter.

4086.

* 4084.

† 4085.

4087.

If a Body be placed in a Sphere that is homogeneous, hollow, and every where of the same Thickness, wheresoever it be placed it has no Gravity, the opposite Gravities mutually destroying one another, as we shall shew in the next Scholium:

4088.

Whence it follows, that in an homogeneous Sphere, a Body, coming towards the Center, gravitates towards the Center only from the Action

4089.

Action of the Sphere, whose Semidiameter is the Distance of the Body from the Center, which Gravity decreases in coming towards the Center, in the Ratio of the Distance from the Center^{*}; for all Matter which is at a greater Distance from the Center, forms an hollow Sphere, in which the several Actions on a Body destroy

* 4088. each other^{*}.

4090. We have said that the Gravity which we have hitherto explained is to be taken for a Law of Nature, because we don't know the Cause of it; and because it depends upon no Cause that is known to us, which will evidently appear, if we attend to what follows.

4091. (*Viz.*) That Gravity requires the Presence of the attracting Body; so the Satellites of Jupiter, ex. gr. gravitate towards Jupiter where-soever it be^{*}.

* 4055.

4092. That the Distance remaining the same, the Celerity with which Bodies are carried by Gravity, depends upon the Quantity of Matter in the attracting Body^{*}: And that the Celerity is not changed, let the Mass of the gravitating Body be what it will^{*}.

4093. * 4067.

4094. Besides that, if Gravity depends upon any known Law of Motion, it ought to be referred to a Stroke from an extraneous Body; and because Gravity is continual, a continual Stroke would be required.

4095. If there be such a Sort of Matter continually striking against Bodies, it must of Necessity be fluid, and very subtile, so as to penetrate all Bodies; for Bodies, that are any how shut up in others, are heavy.

4096. Now let a Mathematician consider, whether a Fluid so subtile, as freely to penetrate the Pores of all Bodies, and so rare, as not sensibly to hinder the Motion of Bodies (for in a Place void of Air the Motion of a Pendulum will be continued very long) can impel vast Bodies towards one another with so much Force?

4097. Let him explain how this Force increases in a Ratio of the Mass of the body towards which another is carried^{*}.

* 4092.

4098. Lastly let him shew, what seems most difficult to me, how all Bodies, in any Situation whatsoever (if the Distance, and the Body towards which the Gravitation is, remain the same) are carried with the same Velocity^{*}; that is how a Liquid which can only act on the Surfaces, either of the Bodies themselves, or their internal Particles, to which it is not hindered from coming by the Interposition of other Particles, can communicate such a Quantity of Motion to Bodies which in all Bodies exactly follows the Proportion of the Quantity of Matter in them; and which in this Chapter we

* 4093. have

Chap. II. of Natural Philosophy.

have proved to obtain every where in Gravity, and which we have demonstrated by a direct Experiment in respect of the Gravity near the Earth's Surface *.

Yet we don't say, that *Gravity does not depend upon any Stroke*, but that it does not follow from that Stroke, *according to any Laws known to us*, and we confess that we are intirely ignorant of the Cause of Gravity.

SCHOLIUM.

Of Gravity towards a Sphere, whether solid or hollow.

LET us suppose the Particle of Matter A to be attracted by an hollow Sphere HPN, which is homogeneous and every where of the same Thickness, whose Center is C; let us suppose also, that all the Particles of Matter of which the Sphere consists, draw the Particle A according to the Laws of Gravity above mentioned *. We shall demonstrate, that the Attraction is the same, whether the Sphere be greater or less, provided it contains the same Quantity of Matter, and has the same Center.

Let C be that Center, as we have said; HN the Diameter of the Sphere, having drawn at Pleasure the Lines AP, *ap*, containing an infinitely small Angle, we conceive that they have a Rotation about the Axis AC, and, while they run over the Surfaces of Cones, that they determine in the Surface of the Sphere a Ring, whose Semidiameter is BG, and Breadth B*b*: we also suppose that the Thickness is inversely as the Surface of the Sphere; that is inversely as the Square of the Radius BC; because we suppose that having changed the Sphere, the same Quantity of Matter remains; so that the Thickness is increased as the Diameter of the Sphere is diminished.

The Quantity of Matter, in that Ring, is then as $\frac{Bb \times BG}{BC^2}$. The Force by which the Ring attracts to itself the Particle A is in that Ratio *, and inversely as the Square of the Distance BA †; wherefore $\frac{Bb \times BG}{BC^2 \times BA^2}$ † would express the Force of the Ring, if that Force was not oblique; but by Reason of the Obliquity it is less in the Ratio of AB to AG *, or AC to AD, having drawn CD perpendicular to AP.

For the rectangular Triangles ACD, ABG, which have a common Angle at A, are similar *. Therefore we may express thus the Force of the Ring $\frac{Bb \times BG \times AD}{AB^2 \times BC^2 \times AC}$.

drawing the Lines AQ, Aq , containing a small Angle; and having made them move round, as we said of AP, Ap , we cut off a Ring whose Radius is FL , and it's Breadth Ff , the Thickness inverfely as the Square of the Semidiameter FC ; and the whole Force with which the Ring will attract the Particle A , drawing CE perpendicular to AQ , will be as $Ff \times FL \times AE$.

* 4104. $\frac{Ff \times FL \times AE}{AF^2 \times CF^2 \times AC}$ *

4106. Now if the Arcs BP, FQ , as also bp, fq , are fimilar, it will appear by the following Demonstration that the Forces of the faid Rings are equal.

4107. Because of the infinitely fmall Angle PAp , the Line CD , which is perpendicular to BP , is alfo looked upon as perpendicular to bp ; fo alfo CE , or Ce , is looked upon as perpendicular to fq ; and, becaufe in thofe different Circles the Chords are correspondent *, therefore the Perpendiculars on them from the Center are proportional;

That is, $CD, Cd :: CE, Ce$.

4108. By Divifion and Altern. $CD, CE :: Dd, Ee$.

* 4103. We have befides $CD, AC :: BG, AB$ *.

4109. As likewise $AC, CE :: AF, FL$.

* 4106. Whence by joining the Ratios CD, CE , or CB, CF * :: $BG \times AF, AB \times FL$.

Therefore $CB \times AB \times FL = CF \times BG \times AF$; whence $\frac{BG}{AB \times CB} = \frac{FL}{AF \times CF}$;

4110. and $\frac{BG^2}{AB^2 \times CB^2} = \frac{FL^2}{AF^2 \times CF^2}$.

4111. We fuppofe the little Arches bm, fn defcribed with the Center A , and we have four fimilar Triangles DCB, ECF, mBb , and nFf . They are all rectangular, and the greater are fimilar becaufe of the correspondent Chords BP, FQ ; for the fame Caufe the Angles mBb and nFf are equal, and the leffer Triangles are fimilar: Likewise each fmaller is fimilar to it's greater; for, becaufe of the right Angle CBb , the Angles CBD, bBm taken together are equal to a right one; to a right one * 32 El. 1. likewise is equal the Sum of the Angles CBD, BCD *, therefore the Angles bBm and BCD are equal.

4112. Thefe Things being fuppofed, the Ratio of Bb to Ff , which is the fame as the Ratio of bm to fn , will be compounded of the following,

* 4109. $b m, Dd :: AB, AD$;
 $Dd, Ee :: CD, CE :: BG \times AF, AB \times FL$ *;
 $Ee, fn :: AE, AF$

Therefore $bm, fn :: Bb, Ff :: AB \times BG \times AF \times AE, AD \times AB \times FL \times AF ::$
 $BG \times AE, AD \times FL$ and

4113. $Bb \times AD \times FL = Ff \times BG \times AE$

* 4110. Now if we multiply this Equation by the foregoing *, the firft Member by the firft Member, and the fecond by the fecond, and divide both the Members of this new Equation by $BG \times FL \times AC$, we fhall have what was to be demonftrated, namely

$$\frac{Bb \times BG \times AD}{AB^2 \times BC^2 \times AC} = \frac{Ff \times FL \times AE}{AF^2 \times CF^2 \times AC}.$$

It

It is plain by a like Demonstration, that two opposite Rings, whose Breadths are Pp , Qq , do also equally attract the Particle A ; which might be demonstrated another Way; for Rings made at the same Time in the same Sphere, as Bb , Pp , act also equally on the Particle A .

4114.

Having drawn many Lines as AP , or rather multiplying their Number infinitely, a whole Sphere HPN , may be divided into Rings by the Revolution of those Lines; then if we conceive a second Sphere to be divided into an equal Number of Rings by the Revolution of such Lines as AQ , which every one cut off an Arc similar to that, which a correspondent Line cuts off in a greater Sphere; each Ring in the least Sphere will act equally with it's Correspondent in the greater.

4115.

Whence it follows, that the whole Action of a smaller Sphere agrees with the whole Action of a greater; and this Action is the same however the Sphere be diminished, if the Quantity of Matter remains; therefore the *Matter acts as if it was condensed into the Center.*

4116.

The same Thing will happen, *if the Sphere be solid, and of the same Density every where, at the same Distance from the Center.* For such a Sphere may be taken for a Congeries of hollow and concentrick Spheres, and like those that we have treated of.

4117.

The Proposition of N^o 4082 being demonstrated, we pass on to the Demonstration of 4088. We suppose the Particle A in the hollow Sphere, Pl. 126. made of homogeneous Matter, and every where of the same Thickness, Fig. 4. to be shut up and put into a Place.

4118.

Let us suppose two opposite Pyramids in the Vertex BAb , AFf . The Triangles ABb and AFf are similar*, and AB or Ab , is to Af * 35 El. 3. or AF , (for we suppose that the Lines BF , bf contain an Angle infinitely small) as Bb to Ff : for from that Similitude of the Triangles it follows that the Pyramids are equally inclined to their Bases, and therefore that the Bases are similar, and to one another in a duplicate Ratio of the Lines Bb , Ff *, or AB , AF ; but these Bases are also as the Quantities of Matter in them; therefore the Particle A is drawn to the opposite Parts by Actions, which are directly in a duplicate Ratio of the Lines AB , AF *; and inversely in the same Ratio; so that the opposite Forces are equal, and mutually destroy one another; therefore as the whole Surface of a Sphere may be divided into the Bases of opposite Pyramids, which will all have A for their common Vertex, it follows that all the opposite Actions of a Sphere destroy one another mutually, and that a Particle of Matter may be at rest in any Part of such a Sphere.

6 El. 6.

* 20 El. 6.

* 4048. 4049.

C H A P. XII.

Of the Celestial Matter ; where a Vacuum is proved.

4119. **H**A V I N G explained the Laws whereby the whole planetary System is governed, several Things must be first laid down before we proceed to the physical Explication of the System. We must begin by saying something of the Celestial Matter, that is of the Medium in which the Bodies that make up the System are moved, which would be done in few Words, if all Philosophers agreed that there is a *Vacuum*.

* 22. We have before proved that a *Vacuum* is possible* ; now we are to demonstrate that there is really one.

4120. *From only considering Motion we can deduce a Vacuum ;* and this is a very common and usual Way of proving it ; to see the Force of which Argument, we must consider, that indeed all Motions are not impossible without a *Vacuum*, but most of those which are daily observed ; which might be fully evinced by a longer Discussion ; But it seems to me to be so evident from the following Consideration, that it would be useless to add much more.

4121. The Figure of the least Particles is unchangeable ; for the Particle, whose Figure may be changed, consists of smaller Particles, which are moved in respect to each other ; and therefore if it has a changeable Figure, it is not one of the least Parts.

4122. But if the Figure of these Particles be unchangeable, and a Body can move between them without such a Separation of the Particles as to leave a void Space ; this will depend on the Figure of the Particles, and the Relation which they have to one another, which a Mathematician will not deny. Therefore, if keeping Things in this State (as to their Figure and Relation) the Particles are increased, even in that Case Bodies may be moved without a *Vacuum*.

4123. Now supposing the smallest Particles increased to the Bigness of a Cubic Foot, whatever be their Figure and Relation with the other Parts, which we suppose increased in the same Proportion as the first ; let any one consider, whether Bodies of any Bigness can be carried between those Parts in right Lines, and in all Sorts of Curves, and yet never separate the Particles so as to leave Vacuities between them.

We

We cannot conceive how the most subtile Parts are made, and therefore often attribute to them such Properties as do not follow from their Figure; but these Errors will be corrected, by imagining the Particles increased.

We also prove a Vacuum by an Argument taken from Resistance.

4124.

We have said that Matter is inactive *; some dispute about the Word, but no Man denies the Thing; whence it follows that a * Body cannot move through a Fluid, without undergoing a Resistance *, and consequently Retardation †. The Resistance arising * from the Inertia of the Matter (which Resistance alone is here considered) depends upon the Quantity of Matter to be removed out of it's Place, which is the same whether the Parts of a Fluid be greater or less, if the Celerity of the Body remains the same: Whence it follows, that in determining what relates to the Resistance, we must have no Regard to the Subtlety of the Fluid, as long as it cannot go through the Pores of Bodies; for if we come to such a Fineness of Parts, that a Fluid shall partly penetrate a Body, it will less resist the Body.

4125.

19.

1885.

† 1953.

Now let us suppose any Ball or spheric Body to be moved along in a Medium of the same Density as itself, and so close, that the Parts of the Medium cannot pass through the Pores of the Body; this Body will be retarded every Moment, so that it's Velocity at last will be reduced to half; as may be proved by a Mathematical Demonstration) before the Body has gone through the Length of it's Diameter and the half of it *.

4126.

* 1974.

In Order to apply this Proposition to a Motion in a very subtile Fluid, which freely penetrates the Pores of all Bodies, and fills all Places, we must conceive a spherical Body without any Pores at all; and that such a Body may be supposed by imagining all the Particles of Matter closely joined, no Body will deny.

4127.

That the Resistance of such a Body in any Fluid does not depend upon the Bigness of the Parts of the Fluid, and is the same whether the Parts of the Fluid be equal, or any how unequal, is evident *.

* 4125.

If every Thing be full of Matter, this Body can only move through a Fluid of the same Density as itself; for it must run against all the Matter which is in those Places through which it passes, and in them the Matter is without Interstices as it is in the Body; therefore it will lose half it's Velocity, before it has run through the Length of it's Diameter and an half.

4128.

Now let us suppose the Body to be increased, the Quantity of Matter remaining the same, and the Body continuing homogeneous; that is, let there be Pores in the Body, through which the most subtile Particles of Matter may pass very freely; and let these Pores be equally dispersed all over the Body. If the Body, thus changed, be moved, the very subtile Fluid, of which we speak, will not run against the whole Surface, but only those Parts of the Surface which are between the Pores, which Parts being taken together, because we suppose the Body homogeneous, are equal to the Surface of the Body in the first Supposition, when we conceived it to be without Pores; for the Body being increased, the Surface has not been changed but only dilated by the Interposition of Pores: So that in both Cases the Body will undergo the same Resistance from the Impulse upon the Surface; and the Resistance on the dilated Body is greater from the Fluid running against the internal Parts of the Body. Wherefore this Body will sooner lose half it's Motion in the second, than in the first Case; that is, before it has run through the Length of one Diameter and an half of the first supposed Bigness; and therefore it loses a greater Quantity of Motion, in going through one and an half Diameters of the Bigness supposed in the second Case.

4129.

But this is contrary to Experience; for a homogeneous Ball of Gold, or Lead, &c. is much less retarded than what we have mentioned, in Water or Air; whence it follows, that the Supposition, that all Things are full of Matter, is false. Therefore there is a *Vacuum*.

4130.

That there is a Vacuum does also agree with the Phænomena relating to Gravity; by which it follows that it is proportional to the Quantity of Matter. If all was full of Matter, Gravity would act equally every Way, and the Forces which are directed towards opposite Parts would destroy one another; and therefore no sensible Gravity would be observed: This Consideration confirms that there is a Vacuum, and illustrates the Assertion; but is not alone sufficient to prove it.

These Things being premised, we must return to the Celestial Matter.

* 4099.

4131.

The Motions of the heavenly Bodies do not depend upon the Motion of the Celestial Matter if there be such a Matter*; *whereby is overthrown the Opinion of those which say that the heavenly Bodies are carried along by the common Motion of the Matter which fills our System.*

This

This Opinion is also overthrown by the Motion of the Comets; if there was a Medium in the System which carried about the Planets in it's Motion, and also the Comets, it would at least sensibly disturb these last in their Motions, whilst they come almost directly towards the Sun, or directly recede from it, or are carried in *Antecedentia*; that is, in a Motion contrary to the Motion of that Matter: Now as this Motion is not disturbed, but follows the Way which depends upon Gravity, as it is observed, it is plain, that if there be any Celestial Matter, and that is in Motion, it does not exert a sensible Action on the Bodies of the planetary System, which is also deduced from the small Resistance of such a Medium; for *by comparing the most ancient Observations with the modern, it does not appear that the Planets are sensibly retarded in their Motions.* Yet in Air the Resistance is sensible; wherefore the Density of the Medium in which the Planets should move, must be almost immensely less; Therefore *the planetary System is not filled, unless it be by such a very subtle Medium.*

4132.

4133.

4134.

But we may from the Divisibility of Matter deduce, that a Quantity of Matter, how small soever it be, may be dispersed all over the planetary System, leaving but very small Interstices *.

* 37.

C H A P. XIII.

Concerning the Motion of the Earth.

BESIDES the Question that has been handled in the foregoing Chapter, there is also another to be examined, before we proceed to the Explication of the whole System.

4135.

That no Doubt may be made concerning the System, which has been explained in the first Chapter of this Book, we must here prove the Motion of the Earth concerning which it is no Wonder that many have doubted; for the Celestial Motions cannot be determined by us but by Observations made by Observers on the Earth; and the same Phænomena appear whether the Bodies themselves be moved, or the Spectator be moved *; so that it is not to be proved * by immediate Observations, whether the Motion of the Earth is to be referred to the heavenly Bodies or not.

3776.

That the Earth is carried about the Sun, is deduced from the Analogy of the Motions, and from an Examen of the Laws of Nature.

4136.

4137. As to what relates to the Analogy of the Motions, it is to be observed, that Satellites revolve about *Jupiter* and *Saturn*, which are less than the central Body; that the Moon revolves about the Earth, than which it is less; *lastly*, That the Sun has revolving about it less Bodies than itself, as *Mercury*, *Venus*, *Mars*, *Jupiter*, and
4138. *Saturn*: Now if the Earth revolves with the rest, then every where in our System the lesser Bodies move about the greater; now there would be an Exception in the Rule in respect of the Sun, if that vast
- * 3748. Body was to go round so small a Body as the Earth*.

About the Sun, *Jupiter* and *Saturn*, about which several Bodies revolve, those move the slowest which are most distant from the central Body, and according to this Rule, that the Squares of the periodical Times follow the Ratio of the Cubes of the Distances*; which Rule may be applied to the Earth, if it be carried about the Sun with the rest of the Planets, as appears, if it's periodical Time, (namely the Time in which the Sun appears to perform an intire Revolution) and it's Distance from the Sun be compared with the Distances and periodical Times of the rest of the Planets.

Now the Rule has only one Exception if the Sun be moved about, and the Earth is at rest.

4140. In this Case *Mercury*, *Venus*, *Mars*, *Jupiter*, and *Saturn*, are subject to this Rule in their Motions, as also the five Satellites of *Saturn* and the four Planets that accompany *Jupiter*; only the Moon and the Sun would move the Earth in a Proportion quite different; and then the Celerity of the Sun would not only be greater than is required by this Law, but it's Velocity would at least be six and twenty Times greater than that of the Moon, though it be removed to a vast Distance from the Earth, in respect to the Moon's Distance: And therefore in this respect, the Analogy of the Celestial Motions would be disturbed.

4141. To these Arguments I shall add others, whereby it will clearly appear, that the Motion of the Earth is a necessary Consequence of the Laws of Nature, which are deduced from Phænomena.

- * 4047. All Bodies gravitate towards one another*, therefore the Sun and
4142. Earth do; but the Motion, whereby these Bodies tend towards one another, is deduced from direct Observations. Whichsoever of these Bodies moves about the other, describes Areas by Lines drawn to the Center of it proportional to the Times which is evident from Astronomical Observations; therefore the Body moved is retained in a Curve by a Force, which is directed towards the Center of the other*. Now as Reaction is always equal to Action†, unless the

* 586.

† 301. 365.

*Laws of Nature, which obtain constantly every where, be wholly overturned, these two Bodies tend towards one another with Celerities that are inverſly as their Maſſes **

* 4092.

The Quantity of Matter in the Earth is next to nothing, in Compariſon to the Quantity of Matter in the Sun, as we ſhall ſhew in the following Chapter; wherefore *the Sun muſt move very ſlowly whilſt the Earth comes towards it very ſwiftly.*

Whence it follows, that the Earth is carried about the Sun, leſt it ſhould fall upon the Sun by that very violent Motion whereby it is retained in it's Orbit *

4143.

* 561.

This Motion of the Earth is alſo deduced from the ſame Principles another Way.

4144.

Two Bodies that are carried towards one another by any Force, will at laſt concur, or continually recede from one another, unleſs each of them be ſo moved, as to have a centrifugal Force equal to the Force whereby it is carried towards the other Body; but as the Bodies which gravitate towards one another, tend towards each other with equal Preſſions *, *theſe Bodies cannot perſevere in their Motions about one another, unleſs both of them be ſo moved as to have equal centrifugal Forces, which does not happen, unleſs they both revolve in equal Times about their common Center of Gravity; that is, if this Proposition be applied to the Sun and Earth, unleſs they both move about a Point, whoſe Diſtance from the Center of the Sun is to it's Diſtance from the Center of the Earth, as the Quantity of Matter in the Earth is to the Quantity of Matter in the Sun, they cannot perſevere in their Motions about one another **. This Point or Center of Gravity muſt of Conſequence be very near to the Sun's Center. Now ſince whichſoever of theſe Bodies moves, it perſeveres in it's Motion about the other, it follows, that both of them are affected by the Motions abovementioned; and that the Sun is moved but a little whilſt the Earth deſcribes a very great Orbit. Whence it follows, that the Motion of the Earth cannot be denied by any one, who reaſons from the Laws of Motion that are deduced from Phænomena.

* 361.

4145.

* 611. 613.

Having proved *the annual Motion of the Earth*, and brought back the Earth amongſt the Planets, there remains but little Difficulty in Relation to the Motion of it *about it's Axis*; for no Body, that believes the annual Motion, doubts of this; a great many, which allow of the Motions about the Axis, deny the annual Motion; therefore it will be enough to obſerve by the by, that all the Planets, concerning which any Obſervations could be made in reſpect

4146.

4147.

ſpect

spect of this Motion, do move about their Axes; and that the Earth has such a Motion, *the uniform diurnal Motion in Bodies, at any Distances, does plainly enough shew.*

To which we must add, that the Celerity of the fixed Stars going through one Revolution in less than 24 Hours, can hardly be more probable than it is conceivable.

4148. This Motion is also disagreeable to the Nature of all the heavenly Bodies; for, *if they are carried round*, they must every Day, with an equable Motion, describe Circles that have the Earth for their Center; that is they must, by Lines drawn to the Center of the Earth, sweep through Area's proportionable to the Times, and be retained in their Orbits by Forces which are directed towards the Center of the Earth *, and by which (by reason that Action and Reaction † are equal) the Earth must also be continually attracted towards *those Bodies*; so that it *must necessarily be agitated by a very violent Motion*; whence it appears that the diurnal Motion must not be referred to the heavenly Bodies, but to the Rotation of the Earth about it's Axis.

4149. Those, that obstinately affirm that the Earth is at Rest, object that Bodies, upon the Surface of the Earth, must (on account of their centrifugal Force) recede from the Earth along a Tangent to a Circle parallel to the Æquator *. We answer, that the Bodies in the Places, where they are, are carried round with the same Motion as the Surface of the Earth; and therefore, that, in respect of the Points of the Surface, they endeavour to recede in Lines perpendicular to the Axis *; but also that Bodies by Gravity tend to the Center of the Earth †; and therefore by a Motion compounded of both these, the Body is continually moved, or endeavours to move *, but because the first Motion is extremely small in respect of the other, a heavy Body is turned but very little out of it's Direction towards the Center, and the Gravity is a little diminished, so much the more as the Place is more distant from the Pole; which agrees with Experience. We shall hereafter shew, when we come to speak of the Figure of the Earth, that the abovementioned Direction of heavy Bodies is every where directed perpendicularly to the Surface of the Earth; which is not exactly spherical.

4150. A Body which is thrown upwards, is acted upon, not only by the Motion wherewith it is thrown up; but it is also carried by the Motion that is impressed to the Person or Machine that impels the Body; that is, it is carried by the Motion which is common with the

the Surface of the Earth; and therefore the Body moves in the same Line (the Line being carried on with the Surface of the Earth) as it would do if the Earth was at rest.

C H A P. XIV.

Concerning the Density of the Planets.

BEFORE we proceed to the physical Explanation of the System, we must determine the Quantities of Matter in some Bodies, and their Densities; which being known, the Effects of the Laws, by which these Bodies are governed, will more easily appear.

4151.

The Quantities of Matter, in different Bodies, are to one another, as the Gravities at the same Distance from these Bodies*; which Gravities are to one another inverfly as the Squares of the periodical Times of the Bodies revolving about those different Bodies at the same Distance*. By multiplying the Quantities which are in this Ratio, by the same Quantity, (*viz.*) by the Cube of this Distance, the Ratio of these Quantities will not be changed; which are therefore to one another as the Quotients of the Divisions of the abovementioned Cube, by the Squares of the periodical Times aforefaid: But the Quotient of such a Division is found for any Body, by dividing the Cube of the other Distance, let it be what it will, by the Square of the periodical Time of the Body revolving at that Distance; for such Quotients are equal to one another, for all Bodies that revolve about the same Body at any Distances; as follows from the Equality of the Ratio between the Cubes of the Distances, and the Squares of the periodical Times at those Distances*. From which we deduce, that *the Quantities of Matter, in any Bodies in our System, are to one another directly as the Cubes of the Distances at which other Bodies revolve about these, and inverfly as the Squares of the periodical Times of these revolving Bodies.*

4152.

4048.

616.

3747.

4153.

These Things are demonstrated by setting aside the Agitation of the central Body, whose Quantity of Matter is sought

4154.

By reason of the Sun's Magnitude, in Respect of *Venus** (for ex.) which alone we consider of the Planets, the Sun is scarce moved by the Action of that Planet*. And *Venus* may be considered as moving about a quiescent Body.

3748.

4092.

The Satellites of *Jupiter* and *Saturn* are indeed carried by the common Motion along with the primary Planets, but by reason of the Magnitude of the primary Planets, they are carried about them as about Bodies that are at Rest.

4155. But the Moon acts sensibly enough upon the Earth and moves it; wherefore before we can compute the Motion of the Moon by

* 4153. the Help of the aforesaid Rule *, in order to compare the Quantity of Matter in the Earth, with the Quantity of Matter in the Sun, *Jupiter* and *Saturn*, we must determine *the Distance at which*

4156. *the Moon would move about the Earth*, if it was at Rest, (that is, *not carried about by the Action of the Moon*,) *in the same periodical Time in which it now performs it's Revolution*. Here also we don't take Notice of the Motion that is common to the Earth and Moon, by which they are both carried about the Sun.

4157. The Moon perseveres in it's Motion about the Earth; therefore the Earth and Moon are moved about a common Center of Gravity; as follows from what has been demonstrated concerning the Earth and the Sun *, and the Moon (with that Force with which it tends towards the Earth) revolves in an Orbit whose Semidiameter is the Distance of the Moon from the aforesaid common Center of Gravity of the Moon and the Earth.

* 4145.

If the Earth was at Rest, and the Moon continued at it's Distance from it, the Moon would move in a greater Orbit, and it's periodical Time would be greater; but the Moon being brought so much nearer as to have it's Center at *sixty Semidiameters* Distance from the Earth, the periodical Time would be the same as the Time of the Revolution about the abovementioned Center of Gravity, as we shall demonstrate in the next Scholium.

These Things being premised, we proceed to the Computation.

4158. The Distance of *Venus* from the Center of the Sun is 723, and
* 3728. it's periodical Time is 19414160" *.

4159. The fourth Satellite of *Jupiter* is distant from the Center of *Jupiter*, 12,4775. such Parts of which *Venus* is distant from the Sun
* 3744. 723. The periodical Time of this Satellite is 1441929" *.

4160. The fourth Satellite of *Saturn* is distant from the Center of *Saturn* 8,5107 of the same Parts, and it's periodical Time is
* 3745. 1377674" *.

4161. Lastly, the Distance of the Moon is 60 Semidiameters of the Earth from it's Center, and 3,054 of the aforesaid Parts. It's

* 3743. mean periodical Time is 2360580" *.

If you divide the Cubes of these Distances respectively by the Squares of their periodical Times, you will have in the Quotients, Numbers which are to one another as the Quantities of Matter in the aforesaid Central Bodies *; which Quotients are to one another * 4153. as the following Numbers: except the Earth concerning which we must have a Correction; because, as we have already observed *, * 4077. the Gravity of the Moon towards the Earth, is by the Sun's Action diminished $\frac{1}{18066}$; therefore the Quantity of Matter discovered was to be increased in the Ratio of 17966 to 18066, which we have done.

Quantities of Matter.	{	<i>In the Sun.</i>	<i>In Jupiter.</i>	<i>In Saturn.</i>	<i>In the Earth.</i>	<i>In the Moon.</i>	4163.
		10000.	9,305.	3,250.	0,0512.	0,0013.	

We have also the Proportion of the Diameters of these Bodies from Astronomical Observations, as follows. 4164.

Diameters.	{	<i>Of the Sun.</i>	<i>Of Jupiter.</i>	<i>Of Saturn.</i>	<i>Of the Earth.</i>	
		10000.	997.	791.	109.	

If the Quantities of Matter abovesaid be divided by the Squares of the Diameters, the Quotients will be to one another as the Weights on the Surfaces of the aforesaid Bodies *; and these Quotients are as the following Numbers. 4165. * 4083.

Gravities on the Surfaces.	{	<i>Of the Sun.</i>	<i>Of Jupiter.</i>	<i>Of Saturn.</i>	<i>Of the Earth.</i>	<i>Of the Moon.</i>	4166.
		1000.	936.	519.	431.	146.	

If you divide these Numbers by the Diameters, you will have the Proportion of the Densities of those Bodies *. 4167. * 4087.

The Quotients, found by these Divisions, are as the following Numbers.

Densities.	{	<i>Of the Sun.</i>	<i>Of Jupiter.</i>	<i>Of Saturn.</i>	<i>Of the Earth.</i>	<i>Of the Moon.</i>	4168.
		10000.	9385.	6567.	39539.	48911.	

We shall determine what relates to the Moon in the last Chapter, but we have added what we have done here, the better to compare it with the rest. 4169.

It is not probable that the aforesaid Bodies are homogeneous, from whence it follows, that the Densities cannot be exactly determined, wherefore we only determine the mean Densities, that is, which the Bodies would have if the same Bodies keeping the same Quantity of Matter and Bulk which they now have, should become homogeneous. 4170. 4171.

The abovementioned Proportion * between the Densities in respect of all the Bodies, and the rest of the Computations in respect of the Sun, Jupiter, and Saturn, are free from any sensible Error; when they are compared with the Earth, there may be some Error, which must be corrected by Observations to be made hereafter, by which the Distance

stance of the Earth from the Sun will be more accurately determined.

4173. Suppose the Distance of the Moon (which is 60 Semidiameters of the Earth) to be 3,054 such Parts, of which *Venus* is distant

* 4161. from the Sun 723 *, that is, of which the Earth is distant from
† 3728.3729. the Sun 1000 †; which Distance of the Moon is discovered by

supposing the Horizontal Parallax of the Sun $10''$, $30'''$, which cannot be looked upon as absolutely true, although it be deduced from the most exact Observations that have hitherto been made, of the Parallax of *Mars*, when it is nearest of all to the Earth, which is too small to leave us without Suspicion of some Mistake *.

* 3925.

4174.

But the Error in not determining truly the Proportion between the Semidiameter of the Earth and the Distance from the Sun, does not change the determined Density of the Earth, as is deduced from Computations made about it *.

* 4162.4166.
4167.

4175.

For it follows from these, that the Densities of Bodies are to one another in a Ratio compounded of the direct Ratio of the Cubes of the Distances of the Bodies carried about, and the inverse Ratio of the Squares of the periodical Times of these revolving Bodies*; as also of the inverse Ratio of the Cubes of the Diameters of the central Bodies whose Densities are required †; the Ratio compounded of these is compounded of the direct Ratio of a Fraction whose Numerator is the Cube of the Distance of the revolving Body, and whose Denominator is the Cube of the Diameter of the central Body, and the inverse Ratio of the Square of the periodical Time of the Body carried about.

* 4162.

† 4165.4167.

4176.

But you have such a Fraction, if you know the Ratio between the Diameter of the central Body and the Distance of the revolving Body from that Center, although this Distance can be compared with no other; but this Ratio is given in respect of the Earth and Moon, as well as in respect of the other Bodies; wherefore also the Ratio of the Density of the Earth to the Densities of the other Bodies is exactly discovered.

S C H O L I U M.

Of the Distance of the Moon, supposing the Earth immoveable.

4177.

WE suppose the Things which are explained in N° 4157; let l be the Distance of the Moon from the common Center of Gravity of the Moon and Earth; t the Distance of the Earth from the said Center. Therefore

Therefore $l+t$ is the Distance of the Moon from the Earth, that is 60,5 Semidiameters of the Earth ; for we consider the mean Distance.

We must determine, if the Earth stood still, that is was immoveable in it's Place, at what Distance the Moon must be removed, to perform it's Revolution about the Earth thus at rest, in a Time equal to that in which it does now, together with the Earth, perform it's Revolution about the common Center of Gravity *.

* 4106.
4178.

Let the Distance sought be x ; and we shall have this Proportion,

$$l, x :: x^2, \overline{l+t}^2.$$

For the Forces, by which the Moon is drawn, when the Distances from the Earth are $l+t$ and x , are to one another as x^2 to $\overline{l+t}^2$ * ; and these * 4049. Forces are as the Distances, at which the Bodies, which are retained by those Forces, would perform their Revolutions in equal Times * : and * 607. those Distances are as l and x .

$$\text{Therefore } x^3 = \overline{l+t}^2 \times l; \text{ and } x^3 \times \overline{l+t} = \overline{l+t}^3 \times l.$$

Whence we deduce $l+t, l :: \overline{l+t}^3, x^3$;

$$\text{And } \sqrt[3]{\overline{l+t}}, \sqrt[3]{l} :: l+t, x.$$

But $l+t$ is to l , as the Quantity of Matter in the Moon and Earth together, is to the Quantity of Matter in the Earth alone ; which Quantities, as we shall see in what follows, are to one another as 40,31, and 39,31 ; the Cube Roots of which Numbers, are 60,5 = $l+t$, to 60 ; to which therefore x is equal, as we said in N° 4157.

C H A P. XV.

The physical Explanation of the whole planetary System.

IN the first Part of this Book we have shewn, what are the 4179. Motions of the Bodies in the planetary System ; now we must explain how these Motions follow from the Laws of Nature * ; * 355. 357. that is, how these Bodies, being once put in Motion, persevere in 361. 4047. those Motions which we observe. 4048. 4049.

Let us conceive the Sun and *Mercury* to be left to themselves, 4180. and they will come together * ; but if they be projected, they may * 4047. revolve about a common Center of Gravity in equal Times, and describe immoveable Elliptic Lines *, and persevere in that Motion ; * 4145. 626. for it is plain, by mathematical Demonstration in that Case, that 4049. the Bodies will describe Ellipses about the common Center of Gravity, similar to that which the one of them could describe with the same Forces about the other if it was at Rest : This Center,

on

* 3748. on Account of the Sun's Magnitude *, is very little distant from the Center of the Sun itself.

4181. Let us conceive besides *Venus* to be projected at a greater Distance from the Sun, it will a little disturb the Motion of *Mercury*, which also, by it's Action upon *Venus*, will turn it a little out of the Way, and both will draw the Sun, sometimes the same Way and sometimes different Ways; but they never come towards one another *

* 3727.3728. so as to have their mutual Action sensible in respect of the Action by which the Sun draws those Bodies; wherefore all these Irregularities are insensible, as we shall shew more distinctly. Whence we conclude that these three Bodies tend towards a Point that is between them near the Sun, which therefore is very little distant from the common Center of Gravity of them all.

4182. If the Earth, *Mars*, and the other Planets be successively projected at different Distances from the Sun, the same Reasoning

4183. will hold good: Whence it follows, that *all the Planets are revolved about the common Center of Gravity of all the Bodies which compose the System*, which is but little distant from the Sun, and that the Planets do not sensibly disturb one another in their Mo-

4184. tions; wherefore *they all describe the same Line singly, which they would describe about the Sun, if every one of them was alone with the Sun in the planetary System*, that is, immoveable Ellipses: For it

* 4049.626. is plain, that those will be described by the Force of Gravity *; and it is proved by mathematical Demonstration, that no other immoveable excentric Lines can be described by a central Force acting equally at equal Distances *.

* 637. It will also more plainly appear, that all the Planets tend to a
4185. Point near the Sun, if we consider that the Quantity of Matter in the Sun is a thousand times, and more, greater than the Quantity

* 4163. of Matter in *Jupiter*, which is far the greatest of all the Planets *.

4186. When *all the Planets move*, though they move *the Sun* but little, yet they do move it, and draw it differently according to their different Situation in respect of one another, whence there arises a small Motion in the Sun, which always depends upon the Motion already acquired, and the Change which happens in it from the Action abovementioned, which varies every Moment.

4187. It is owing to this Agitation of the Sun, that the Planets disturb one another less in their elliptic Motions round the Sun, than if the Sun was at Rest in the Middle of the System. If *Jupiter* (ex. gr.) was equally distant from *Mercury* and the Sun, it would attract both

* 4092. these Bodies to itself with an equal Celerity *, whence the Situation, in

in respect of the Sun, is less changed than if the Sun was not agitated by this Motion, and *Mercury* only was attracted by *Jupiter*: According to the various Distances of *Mercury* and the Sun from *Jupiter*, the one or the other is more attracted, and there is always a less Change in their respective Situation when both are carried the same Way, than if (the Sun being at Rest) *Mercury* only should be carried towards *Jupiter*.

This Reasoning may be applied to all the Actions of the Planets, that are more distant from the Sun, upon those that are less distant. As to what relates to the Action of those that are nearer, upon those that are farther from the Sun, according to the different Situation they draw a Planet to the Sun, or drive it from the Sun, and in considering one whole respective Revolution, that is, the Motion from one Conjunction to another, the Disturbance is less than if the Sun was immoveable.

4188.

The Magnitude of the Sun, compared with the rest of the Bodies of our System, is the Reason (as appears by what has been already demonstrated) *that the Planets disturb one another but little*; but since the Magnitude is not infinite, these mutual Actions must not be wholly overlooked, and therefore it will not be unuseful to make some Computations about them.

4189.

We have said, that it appears by Astronomical Observations, that *Jupiter* alters the Way of *Saturn* when it is nearest to it*; * why this Disturbance is more sensible than the rest is deduced from the Law of Gravity.

4062.

The Actions of *Jupiter* upon *Saturn* when it is nearest to it, and of the Sun upon the same Planet, by which it is kept in it's Orbit, are to one another directly as the Quantities of Matter in *Jupiter* and the Sun*, (viz.) as 9,305 to 10000 †, and inverfly* as the Squares of the Distances of *Jupiter* and the Sun from *Saturn*, that is directly as the Squares of the Numbers 954, 434; for the Distances of *Saturn* and *Jupiter* from the Sun are as 954 to 520*; wherefore, when *Jupiter* is nearest to *Saturn*, the Distances of *Saturn* from *Jupiter* and the Sun are in the said Ratio. The Ratio compounded of the two aforesaid Ratio's, is as 45 to 10000, or as 1 to 222; this Action of *Jupiter* conspires with the Gravity of *Saturn* towards the Sun, and therefore increases it $\frac{1}{222}$ Part: Whence it is no Wonder that the Disturbance is sensible.

4190.

4048.

4163.

3731.3732.

4191.

We don't here consider the Force by which *Jupiter* attracts the Sun, for the Orbit of *Saturn* is not changed by it, and what we had

4192.

had to explain was why Astronomers observe *Saturn* to be turned out of the Way; yet by the Action of *Jupiter* upon the Sun, the Sun is brought nigher to *Saturn*, and the respective Situation of these Bodies is more disturbed, than is discovered by Astronomical Observations. The Force with which *Jupiter* in the aforesaid Position attracts the Sun, and with which therefore the Sun is attracted towards *Saturn*, is to the Force with which *Jupiter* attracts

- * 4045. *Saturn* as 434 squared to 520 squared *, that is as 31 to 45, which Number expresses the Force with which *Saturn* tends towards *Jupiter*, when the Gravity of *Saturn* towards the Sun is expressed by 10000. If we collect into one Sum the Forces of *Jupiter*, by which it attracts *Saturn* and the Sun; the Force, by which, from the Interposition of *Jupiter*, these Bodies tend toward each other, will be to the Gravity of *Saturn* towards the Sun, as 76 to 10000; but this Gravity is to the Gravity of the Sun towards *Saturn*, as
- * 4048 4163. 10000 to 3, 25 *, wherefore the mutual Access, or Approach of the
4193. Sun and *Saturn*, is to the Increase of this Approach by the Action of *Jupiter* interposed, as 10067 to 76, or as 131 to 1.

This Disturbance is remarkable, and far the greatest of any that happens in the Motion of any of the primary Planets; this also obtains only in this one Case of the Conjunction; for when *Jupiter* recedes from *Saturn*, the Disturbance of the Motion of *Saturn*, in a short Time becomes insensible.

4194. In the same Position of *Jupiter*, when it is nearest to *Saturn*, the Force of *Saturn*, although it be the greatest of all in this Case, does not so sensibly alter the Way of *Jupiter* about the Sun. The Action of *Saturn* attracting *Jupiter*, is to it's Action by which

- * 4040. it attracts the Sun, as 954 Square to 434 Square *, therefore it attracts *Jupiter* with greater Celerity; and since they are both attracted the same Way, the Difference of these Forces is the Force, with which (from the Action of *Saturn*) *Jupiter* and the Sun are
- * 918. separated from each other *; which is therefore to the Gravity of the Sun towards *Saturn*, as the Difference of those Squares, to the last; that is nearly as 72 to 19; but this Gravity of the Sun towards *Saturn* is to the Gravity of *Jupiter* towards the Sun, as 3, 25 to

- * 4048. 4163. 10000 *, and as 520 Square to 954 Square †, that is as 19 to
- † 4049. 17509; therefore the disturbing Force of *Saturn* is to the Gravity
4195. of *Jupiter* towards the Sun as 72 to 19509, or as 1 to 2703; therefore by the greatest Action of *Saturn*, the Gravity of *Jupiter* towards the Sun is diminished by $\frac{1}{2703}$ Part, which Disturbance is insensible.

The

The other mutual Disturbances of the Planets are much less, as will appear by determining that, which is the greatest of them all, (viz.) that of *Mars* by *Jupiter*, which is discovered by the same sort of Computation as the foregoing.

4196.

The Distances of *Jupiter* from *Mars*, and the Sun when *Mars* is between the Sun and *Jupiter* in the same Line, are as 3677 to 5201 *; wherefore the Forces with which *Jupiter* attracts these Bo- * 3730.3731. dies, are inversely as the Squares of those Numbers †, that is nearly † 4049. as 2, to 1. the Difference of which Forces is equal to the last, that is to the Gravity of the Sun towards *Jupiter*. This Gravity of the Sun towards *Jupiter* is to the Gravity of *Mars* towards the Sun, as 9,305 to 10000 *, and inversely as the Squares of the Distances of those * 4048.4168. Planets from the Sun †, and this Ratio is compounded of 1 to † 4049. 12512, in which Ratio therefore is the disturbing Force of *Jupiter*, to the Gravity of *Mars* towards the Sun. Wherefore the Gravity of *Mars* towards the Sun is only diminished $\frac{1}{12512}$ by the Action of *Jupiter* when it is near it.

4197.

4198.

Although these Disturbances, arising from the Actions of the Planets upon each other, be very small, and although those, which happen in a different Position of the Planets, do in some Measure compensate each other; yet the Proportion in which the Force, which keeps the Planets in their Orbits decreases, is a little changed by these Actions, so that it does not decrease exactly in an inverse Ratio of the Square of the Distance: therefore although the Orbits are at Rest as to Sense, after a great many Revolutions, a small Change is observed in the Situation of their Orbits *.

4199.

* 630.3696.

From all this it follows, that if we suppose the Planets at first once projected at the Distances from the Sun at which they are moved, they will by the Laws already explained persevere in those Motions; and the Excentricity of the Orbits depends upon the Celerity and Direction of the first Projection. But these Motions may be preserved very long, by reason of the small Resistance of the celestial Matter.

4200.

It is also plain, why, by Lines drawn to the Center of the Sun, they describe *Areas* proportionable to the Times; namely, because all other Gravities in the System, are very small in respect of the Gravity towards the Sun *; therefore by this Gravity alone, it is * 4184. that the Planets are retained in their Orbits, whence follows this Proportion of the *Areas* †.

4201.

† 585.

And also the Motion in elliptic Lines, which are carried on very slowly, follows from the Law of Gravity; for these Lines would

4202.

* 626. 4049. be immoveable, if the Planets gravitated only towards the Sun *; but this *slow* Motion of the Orbits is deduced from the Action of the Planets upon one another †.

‡ 4199. Now in respect to the Proportion which is observed between the
4203. Cubes of the Distances, and the Squares of the periodical Times, it
* 621. 4049. is also deduced from the Law of Gravity *; so that if we add to
† 4052. 4191. these what we have said of the Deflection of *Saturn* †, nothing
will remain to be explained in respect of the primary Planets.

4204. That *the Motion of Comets depends upon the Law of Gravity*, is
also deduced from Observations; and in respect of them, as has been
said concerning the Planets, the Sun's Gravity prevails, and by that
* 3754. 586. Gravity they reflect from a rectilinear Course *; but that the Cur-
vature of their Way depends upon the same Gravity, follows from
this; that a Body, by that Gravity, will describe an Ellipse, or a
* 626. 628. Parabola, or an Hyperbola *; which Lines it appears that those
Comets have described, whose Trajectories have been determined.

4205. *The Satellites of Jupiter and Saturn are moved by the same Laws*
* 3712. 3739. *about their Primaries, as the Primaries are moved about the Sun* *;
3747. wherefore the Explication of those Motions † may be also referred
‡ 4200. to them; for in these three Cases, smaller Bodies are revolving at
different Distances about a much greater Body: namely, Satellites
about *Jupiter* and *Saturn*, and primary Planets about the Sun.

4206. *Whilst secondary Planets are moved about a primary one, it is evi-*
dent that they may all be moved with one common Motion, whereby
the respective Motions with which they are moved, in respect of
each other, will not be disturbed, because a Body may at the same
* 359. Time be moved by different Impressions *: The Motion that a
primary Planet has in common with it's Satellites, is the Motion
of a primary Planet about the Sun.

4207. *Yet the Motion of the Secondaries is disturbed by the Action of the*
Sun, towards which they are carried sometimes faster, and some-
times slower, according to the different Position of the Primary;
and they also often concur towards the Sun's Center in different
Directions. These Irregularities, which are very small, cannot be
observed in the Satellites of *Jupiter* and *Saturn*, though they be
really like those which are observed in the Motion of the Moon;
the least Deviation of this last is very sensible to us. But that the
Irregularities of the Moon exactly follow from the Theory of Gra-
vity, will appear in the next Chapter.

SCHOLIUM.

Concerning Bodies revolving about a common Center of Gravity.

LET there be two Bodies of any Bigness attracting one another in the Ratio of the Quantity of Matter in them; let those Bodies be placed at a and b , let b be kept back, and a be projected along ad , which when it is drawn from b describes a Curve, of which ae is a very small Part: Whilst the Body by the projectile Motion runs through ad , it does by the Motion caused by Gravity go through de parallel to ab . 4208.
Pl. 126.F.5.
* 4048.

Let us suppose the same Bodies to be moved afunder to the same Distance as in the foregoing Case, and to be placed in A and B ; and therefore that ab and AB are equal.

Let the common Center of Gravity of the Bodies be C ; and let them be both projected in the Parallels AD , BF , with Velocities that are to one another as the Distances from the Center of Gravity AC , BC , so that the Bodies may whirl about the same Center.

Let us suppose besides that the Angles DAC , CBF are equal to the Angle dab ; and that the Velocities along ad are to the Velocities along AD and BF , as ab is to AC and BC , so that ad , AD , and BF are run through in equal Times, supposing them to be to each other as ab , AC , CB . By Gravity they come to each other in that Time through the little Space de , which is run through by one Body alone a when b is kept back; but when both are left to themselves, that little Space is so described by both, that $DE + GF = de$, in the same Manner that $AC + CB = ab$. Besides DE , is to FG , as AC is to CB *; therefore de , DE , FG , are to one another, as ab , AC , CB ; but as de is parallel to ab , and DE , as also GF , are parallel to AB , the Triangles ade , ADE , BFG are similar; as also ae , AEC , BGC , and the Changes of Velocities are also alike.

This happens in the first Moment of those Motions; and the same Things happen in the following Moments, and the Triangles, whose Bases are run through in correspondent Times in the three Figures, are always similar; and as these whole Figures are made up of these Triangles, respectively similar, they are also similar, and run through in equal Times, as we have said in N° 4180. 4209.

C H A P. XVI.

The physical Explication of the Moon's Motion.

4210. **I**T is certain that the Moon and Earth having once a projectile Motion given them, they can persevere in their Motion about their common Center of Gravity *; if they be carried any Way by a common Impression directed in parallel Lines, as was said of the Satellites of *Jupiter* and *Saturn**, this Motion will not disturb the Motion about the common Center of Gravity, which will follow that Direction only, because in respect of the two Bodies it is at Rest. But the Bodies are carried by a Motion compounded of that Impression, and of the Motion about the common Center of Gravity, which will follow that Direction only, because in respect of the two Bodies it is at Rest. But the Bodies are carried by a Motion compounded of that Impression and of the Motion about the common Center of Gravity *; that is, they are whirled about that Center as it is carried along, as before it's Motion when it was at Rest. If every Moment new Impressions common to both the Bodies act upon them, the Way of the Center of Gravity may be changed every Moment, which Change will be like that which the Bodies themselves would undergo, if they had no respective Motion.

4211. Hence we deduce, that if whilst the Moon and Earth are whirled round their common Center of Gravity, they be both projected, the Way of the Center of Gravity, by the Action of the Sun acting upon both Bodies, is the same as a Body projected in the same Manner, would describe about the Sun.

4212. Whence it follows, that *the Moon disturbs the Motion of the Earth, and that the common Center of Gravity of those Bodies describes that Orbit about the Sun which we have hitherto said that the Earth described*; because we hitherto overlooked the Action of the Moon; but *the Earth describes an irregular Curve*.

4214. Let the Sun be at S; and the common Center of Gravity of the Moon Q, and the Earth M, at the Time of the full Moon, be at F: After one whole Luration, that is, the next full Moon, let that Center be at A; and let F D A be the Orbit which we call that of the Earth; but in which the Center of Gravity above-mentioned does really move.

Pl. 126.
Fig. 46.

If this Lunation be divided into four equal Parts after the first, the Center of Gravity will be at E, the Moon at P, and the Earth at L; after the second Part of the Time, at new Moon, the Center of Gravity will be at D, the Moon at R, and the Earth at I; in the following Quadrature, the Center of Gravity will be at B, the Moon at O, and the Earth at H; lastly at full Moon the Center of Gravity being at A, the Moon will be at N, the Earth at G: all which follows from the Revolution of the Earth and Moon about their common Center of Gravity, whilst it is carried in the Orbit about the Sun.

Therefore we see the Earth moves in the Curve M L I H G, which is twice inflected in each Lunation; which Curve also does not return into itself, because the Inflections in the several Revolutions about the Sun do not coincide; for 12 Lunations, and a third Part of another, are performed every Year.

4215.

This Irregularity of the Motion of the Earth, which is deduced from the Laws of Nature, *is too small to become sensible in Astronomical Observations*; wherefore we may without any Error say, that the Center of the Earth itself describes the Orbit F D A; for M F, or D I, the greatest Distance of the Earth from that Orbit is about the 40th Part of the Distance M Q, which Distance itself is not the 300th Part of the Distance F S.

4216.

In explaining what relates to the Moon, we also neglect the Consideration of the Motion of the Earth about the common Center of Gravity abovementioned, but we suppose it to revolve at the Distance of 60 Semidiameters, from the Center of the Earth; because, as we have before demonstrated*, such is the Distance at which in it's* periodical Time, it could revolve about the Earth at Rest, or carried along in an Orbit in which it should not be disturbed by the Moon's Action. By this Method, the Moon's Irregularities will be much more easily discovered; for they are the same; as is evident whether the Moon moves about the common Center of Gravity of the Moon and Earth, or about the Center of the Earth itself.

4217.

4157.

Let S be the Sun; T the Earth; and the Orbit of the Moon A L B I; and last of all let the Moon be at A in the Quadrature; it tends towards the Sun in the Direction A S, in the same Manner, and with the same Celerity that the Earth is carried towards S along T S, because the Distances A S and T S are equal: This Celerity may be represented by T S or A S, the Action with which the Moon endeavours to descend along A S, and resolved into two Forces.

4218.

Plate 127.

Man-Fig. 1.

Forces by drawing the Parallelogram $ADST$; so that the Moon will endeavour to move in the Directions AD and AT , the Celerities represented by those Lines *.

* 360.

4219.

By the Pression which acts along AD , the Moon is carried with the same Celerity and the same Way as the Earth; by reason of the equal and parallel Lines TS and AD ; wherefore by this Motion, the Relation between the Moon and Earth is not changed; but the Pression along AT conspires with *the Gravity of the Moon towards the Earth*, and this Gravity is increased by the *Action of the Sun, when the Moon is in the Quadratures; and the Augmentation or Addition is to the Gravity of the Earth towards the Sun, as AT the Moon's Distance from the Earth is to TS , the Earth's Distance from the Sun*. That those Pressions along AT and TS are represented by those very Lines, is plain from this, that the Gravities are Pressions, which act on Bodies in Motion in the same Manner as on Bodies at Rest *; and which therefore every Moment generate Augmentations of Velocities in the Ratio of the Gravities themselves †; in which Ratio therefore are the Velocities produced in the same Time.

* 371.

† 4048. 133.

4220.

TS the Earth's Distance from the Sun remaining the same, the abovementioned Addition of Gravity increases and diminishes in the Ratio of the Line AT , the Distance of the Moon from the Earth.

4221.

But this Distance of the Moon from the Earth AT , if it remains the same and TS be increased, then AT would be less in respect of TS ; therefore though there should be no Change in the Force, whereby the Earth and Moon fall towards the Sun, the Addition would be less, and so much less as TS is greater, because this, though increased, would still represent the same Quantity; therefore the Addition will be inversely as TS ; but the Force of Gravity does not remain the same, when TS is increased, but is diminished; wherefore also in that respect the abovementioned Addition is diminished, and in the same Ratio with that Force of Gravity; therefore in the inverse Ratio of the Square of the Distance TS *; if this Diminution be added to that abovementioned, we see that the *Addition of which we speak, follows the inverse Ratio of the Cube of the Distance of the Earth from the Sun.*

* 4049.

4222.

4223.

The Distance of the Earth from the Sun remaining the same, the Gravity of the Moon towards the Earth decreases more slowly in the Quadratures, than according to the inverse Ratio of the Square of the Distance from the Center of the Earth; for if the Addition in that Case should follow the inverse Ratio of the Square of the Distance,

as the Gravity from the Action of the Earth does*, this Ratio* 4049.
would not be disturbed; but the Addition increaseth when the Gravity itself is diminished; wherefore the Addition, when the Distance is increased, is always greater than is required, and consequently the Diminution of Gravity is the less.

This Addition is determined *in the mean Distances of the Moon from the Earth, and of the Earth from the Sun*: Let A T and T S be these mean Distances; the Addition required is to the Gravity of the Earth, towards the Sun, as A T to T S*; the Gravity of the Earth towards the Sun, is to the Gravity of the Moon towards the Earth (because these Bodies are retained by these Gravities in their Orbits) directly as T S to T A, and *inversely as the Square of the periodical Time of the Earth about the Sun, to that of the Moon about the Earth**: Therefore the Addition sought is to the Gravity* 618. 4093.. of the Moon towards the Earth, in a Ratio compounded of these Ratios; that is the abovementioned inverse Ratio of the Squares of the periodical Times of the Earth and Moon, the other Ratios destroying one another. These Times are given, and their Squares are inversely as 1 to 178,73.

Now if the Moon be at L, in which Situation the Sun attracts the Moon and Earth in the same Line, but not equally; the Moon it draws with a greater Force, because it is less distant from it: The Difference of those Forces is the Force by which the Moon is drawn back from the Earth, and by which the Gravity of the Moon towards the Earth is diminished. 4225.

The Forces whereby the Moon at L, and the Earth at T, tend towards the Sun, are to one another as the Squares of the Lines S T and S L*: and the Difference of the Forces, that is, the disturbing Force, is to the Force by which the Earth descends toward the Sun, as the Difference of those Squares to the Square of the Line L S; that is, nearly as double L T to L S or T S; for these Lines do but very little differ from one another; and the Difference of the Squares, whose Roots differ but little, is keeping the Proportion double that which is between the Roots. 4226.

If therefore T S, as before, represents the Force whereby the Earth descends towards the Sun, L l will represent the disturbing Force and diminishing Gravity; when A T represents the disturbing Force in the Quadratures*. Let the Moon be at l; it is again* 4219.
(together with the Earth) attracted by the Sun in the same Line; 4228..
but the Earth, because less distant, moves more swiftly towards the Sun; so that there is a Force which separates the Earth from the Moon,

* 4225. Moon, namely, the Difference of the Forces which attract the Moon and the Earth *, which Force always acts contrary to the Gravity of the Moon towards the Earth, and diminishes it, in the same Manner as has been demonstrated from the greater Gravity of the Moon towards the Sun, supposing it at L. At l also the separating Force scarce differs from the separating Force at L, for this Force, as we have shewn, is proportional to the Difference of the Squares of the Lines TS and LS; and that (as appears by such another Demonstration) proportional to the Difference of the Squares of the Lines lS , and TS; which Differences, by reason that Ll is very small in respect of TS, scarce differ among themselves; so that the Force which diminishes the Moon's Gravity at l , is also represented by Ll .

4229. Yet the disturbing Force is something greater at the Conjunction L, than at the Opposition l ; for supposing the Differences between the Roots to be equal, the Squares keeping the Proportion, will differ so much the more, the less they are, and so keeping the Proportion, the Forces differ more at L and T, than at T and l , which also are less *.

* 4049. From this we conclude, that the Force, which diminishes the Gravity of the Moon in the Syzygies, is double that which increases it in the Quadratures; namely, as Ll to AT. Wherefore in the Syzygies the Gravity of the Moon from the Action of the Sun is diminished by a Part, which is to the whole Gravity, as 1 to 89,36; for in the Quadratures, the Addition of Gravity is to the Gravity, as 1 to 178,72 *.

* 4224. In the Syzygies, the disturbing Force follows the same Proportion
4231. with half added to it; that is with the disturbing Force in the Quadratures *; it is therefore directly as the Distance of the Moon from
* 4230. the Earth †, and inversely as the Cube of the Distance of the Earth
† 4220. from the Sun ‡.
‡ 4222.

4232. At the Syzygies, the Gravity of the Moon towards the Earth, receding from it's Center, is more diminished than according to the inverse Ratio of the Square of the Distance, from that Center; for it would be diminished in that Ratio, if the Force to be taken away followed the same Ratio; but on the contrary, as it increases when the Distance becomes greater *, the Diminution is always greater than in that Ratio, which is the inverse of the Square of the Distance.

* 4231. Lastly, let the Moon be at F, in any immediate Place between the Syzigy and Quadrature, it is drawn towards the Sun along FS,
4233. by

from which since it is less distant than the Earth T, it is attracted with more Force than the Earth: Let the Force with which the Moon tends to the Sun, be to the Force with which the Earth is carried towards it as FM to TS, which also before has been made use of to express the same Gravity of the Earth. Draw the Parallelogram FHMI, whose Diagonal is FM, and whose Side FH is parallel and equal to the Line TS. The Gravity of the Moon towards the Sun is resolved into two Forces, one along FH, the other along FI, and these Lines denote the Pressures whereby the Moon endeavours to move along them*. The Action along FH* 360. is common to the Moon and the Earth, which with an equal Force, and in a Line parallel to it, does also tend to the Sun; so that by this Motion of the Moon the Situation of it, in respect of the Earth, will not be changed, and the disturbing Force will be only the Pressure along FI.

By reason of the immense Distance of the Sun, the Part MS of the Line MF is small, in respect of the whole, and the Angle FST, where it is the greatest, as AST, is hardly more than the 6th Part of a Degree; whence it follows, that the Lines MI and SN are very near one another, and that the Points I and N are scarce sensibly distant, and may without any sensible Error be confounded together; which Error, notwithstanding how little soever it need be regarded, in Consideration of one whole Revolution, is compensated by a contrary Error when the Moon is at E. Therefore the disturbing Force is expressed by FN. 4234.

It is to be observed, when only the Part EF of the Line ES is considered, that is to be looked upon as parallel to the Line Ll, because of the small Angle which these Lines make. 4235.

From the Point N draw NQ perpendicular to the Line FT, continued if Need be, in which the Moon gravitates towards the Earth; and let the rectangular Parallelogram FPNQ be drawn; let us conceive the Force along FN resolved into two others, acting in the Directions FQ and FP, and represented by these Lines*: By the Action along FQ, the Gravity is diminished, in the Case represented by this Figure; but it is increased when the Point Q falls between F and T; but by the Pressure along FP the Moon in it's Orbit is drawn towards the next Syzygy L, and the Motion of the Moon is accelerated or retarded, according as this Force conspires with, or acts contrary to, the Moon's Motion. 4236. 360.

4237.

Near a Syzygy, the Gravity of the Moon is diminished, and the Line F Q, which follows the Proportion of this Diminution grows less, receding from the Syzygy till it vanishes, at the Distance of about 54 Deg. 44 Min. from it; at a greater Distance of the Moon from the Syzygy, Q falls in between F and T; and the Gravity of the Moon towards the Earth is increased by the Sun's Action.

4238.

The Force along F P vanishes in the Syzygy L, receding from it, it increases quite to the Octant, which is the middle Point between the Syzygy and the Quadrature; and then it diminishes again till it vanishes quite at B.

4239.

Between B and l, or l and A, the disturbing Motions are determined in the same Manner, as in A L B, the opposite inferior Part of the Orbit; at E and F, the Diminution of Gravity is equal, and in that Position it is drawn in the Orbit with an equal Force towards the Syzygy l, with that with which at F it is impelled towards the Syzygy L.

4240.

Hence it follows, *that in the Motion of the Moon from the Syzygy to the Quadrature, between L and B, as also between l and A, the Gravity of the Moon towards the Earth is continually increased, and the Moon is continually retarded in it's Motion.*

4241.

But in the Motion from the Quadrature to the Syzygy, between B and l, as also between A and L, every Moment the Moon's Gravity is diminished, and it's Motion in it's Orbit is accelerated.

4242.

You may determine the Forces upon which these Effects depend, by comparing them with the known Force, whereby Gravity is

* 4224.

increased in the Quadratures*, and which is represented by the Moon's Distance from the Center of the Earth.

4243.

The Lines M I, H F, S T, are equal by Construction; therefore when the Points I and N are confounded, M N is equal to S T, and M S is equal to N T. The Lines M F and S T represent the Forces, whereby the Moon at F and the Earth at T are carried towards the Sun S; therefore they are as the Square of the

* 4049.

Line T S to the Square of the Line F S*; wherefore, as F G is the Difference of these Lines, F M and T S differ from one another

† 4226.

double the Line G F †, and adding G F to the Line F M, the Difference between G M and T S, that is, M S will be triple the Line F G, and therefore this is also the Quantity of the Line

* 4235.

N T: Now as F E is double F G*; therefore N T will be to F E as Three to Two.

Let FT be continued, if Need be, and from E draw EV perpendicular to it; the Triangles EVF and NQT, which are rectangular, will be similar, by reason of the alternate Angles VFE and QTN*: Therefore NT is to FE, that is, Three is to Two,* 4235. as NQ, equal to FP is to EV; which therefore is proportional to 29. El. I. two third Parts of the Force, which is expressed by FP; but EV is the Sine of the Angle ETV at the Center which is double the Angle EFV at the Circumference*, equal to the Angle FTL,* 20. El. III. which is the Distance of the Moon from the Syzygy. Therefore, III. *as the Radius TA or TE is to a Sine and an half of double the Distance of the Moon from the Syzygy, namely FP, so the Addition of Gravity in the Quadratures (which is expressed by the Radius TA) is to the Force which accelerates or retards the Motion of the Moon in it's Orbit.* 4245.

The Computation of this Diminution of Gravity, and of it's Increase at a less Distance from the Quadratures, is deduced from the same Principles.

This Diminution is represented by the Line FQ, which is equal to QT minus the Radius; but from the Consideration of the Triangles abovementioned, VF, taken one and a half is equal to QT; therefore VT and an half, with half the Radius added to it, expresses the required Diminution of Gravity; and *the Radius is to the Sum or Difference of one and a half the Co-sine of double the Distance of the Moon from the Syzygy and half the Radius. As the Addition of Gravity in the Quadratures, to the Diminution or Increase of Gravity in that Situation of the Moon, concerning which the Computation is made.* 4246. 4247.

We make use of the Difference of the Co-sine from half the Radius, when the Angle is such whose Co-sine is greater than a right Angle; because in that Case we make use of the Co-sine of the Complement of the Angle to two right Angles: When in this same Case the Co-sine and a half, which we make use of, is greater than half the Radius, the Quantity found is to be added; that is, increases the Gravity; which obtains every where between the Quadrature, and 35 Deg. 16 Min. from it. 4248.

These Forces, whatever is the Figure of the Moon's Orbit, are exactly determined; for they are compared with the Addition of Gravity in the Quadratures, supposing the Moon in the Quadrature to be at the same Distance from the Earth, at which it really is in the Place which is considered; but this Addition is discovered in every Case.* 4249. * 4224. 4222. 4220.

4250.

Though it be foreign to the Purpose of this Work, to give a Computation of the Moon's Motion, I thought it necessary to explain in a few Words, what is the Method whereby to discover the Forces that govern the Moon; because the more exactly we know the Forces, the more easily we shall conceive their general Effect.

4251.

* 638. 4049.

Now to examine the Moon's Motion, we must singly consider it's several Irregularities; which to do without Confusion, we must remove several Irregularities, and conceive the Moon as moving in a Circle about the Earth in which Curve it is plain, that it can be retained by Gravity*. We also conceive that the Orbit of the Moon is in the Plane of the Ecliptick.

4252.

This Motion is disturbed by the Action of the Sun, and *the Orbit is more convex in the Quadratures than in the Syzygies*. The Convexity of a Curve which a Body describes by a central Force, is so much the greater as the central Force does more strongly every Moment turn the Body out of the Way; it is also greater the more slowly the Body moves; because the central Force, acting the longer, has a greater Effect in inflecting the Way of the Body. From contrary Causes the Convexity of the Curve is diminished. Both concur in increasing the Convexity of the Orbit in the Quadratures*, and diminishing it in the Syzygies†.

* 4240.

† 4241.

4253.

4254.

From this it follows, that the circular Figure of the Moon's Orbit is changed into an Oval, whose greater Axis goes through the Quadratures; so that the more convex Parts are in the Quadratures. Wherefore *the Moon is less distant from the Earth at the Syzygies, and more at the Quadratures*, and it is no Wonder that the Moon comes towards the Earth in the Syzygies, when it's Gravity is diminished; because the Access is not the immediate Effect of this Diminution, but of the Inflection of the Orbit towards the Quadratures.

4255.

* 3740. 626.

4049. 636.

The Motion of the Moon, taking away the Action of the Sun, is not in a Circle, but in an Ellipse, one of whose Foci coincides with the Center of the Earth*; for the Orbit of the Moon is ex-centric, and it is retained in it by the Force of Gravity.

4256.

Therefore what has been demonstrated cannot be exactly applied to the Moon's Motion; for as the Forces which generate the Deviations explained, do really act upon the Moon, the Ellipse, which the Moon would describe if the Sun was taken away, is changed, and *cæteris paribus, the Propositions of N^o 4252, 4254. may be applied to the Moon's Motion*. That is, the Figure of the Ellipse (which the Moon would describe if the Sun was taken away, in any

any Situation of the Sun) the Sun being present, is a little changed, the Parts, which are in the Quadrature, become more convex, when on the contrary those that pass through the Syzygies lose of their Convexity; whence necessarily follow Variations in the Distances.

In the Quadratures and Syzygies, the disturbing Force acts in the same Line as the Force of Gravity towards the Earth *; therefore the Force which continually acts upon the Moon, and retains it in it's Orbit, is directed towards the Center of the Earth, and *the Moon describes Area's by Lines drawn to the Center of the Earth proportional to the Times* *.

In other Points of the Orbit, as F besides the Force which acts in the Line FT, there is also another, whose Direction is perpendicular to FT *, which is here represented by FP: the Direction of the Force compounded of both is directed by Degrees sidewise to the Line FT, and does not tend to the Center of the Earth †; wherefore *the Areas by Lines drawn to the Center of the Earth are not exactly proportional to the Times* *. In the Octants, FP is the greatest of all; and the Force which is represented by that Line is to the Gravity of the Moon towards the Earth, in that Point, in the mean Distances of the Sun and Moon, as 1 to 119, 15 *. Wherefore the Direction of the Force, compounded of the Actions of the Sun and Earth upon the Moon, makes an Angle of about half a Degree with the Line FT.

The Motion of the Moon is subject to several other Irregularities; so that it describes a Curve wholly irregular; which *Astronomers*, in order to subject it to the most exact Computations that can be made, do *reduce to an Ellipse which they conceive to be agitated by various Motions, and also to be changeable, lest the Moon should go out of it.*

In respect to central Forces we have observed, that a Body does not describe an Ellipse, if the central Force, by which it is retained in it's Orbit, decreases in any other Ratio than the inverse Ratio of the Square of the Distance; but that the Curve may be often reduced to a moveable Ellipse *, concerning which it is to be observed that the Ellipse, in that Motion, turns about *one of it's Foci, and the Motion of the Ellipse is directed sometimes the same Way as the Motion of the Body* *; and *sometimes the contrary Way.*

Hence it follows, the Orbit of the Moon cannot be referred to an elliptic Orbit, unless you suppose it agitated by four Motions every Revolution; that is, unless the Line of the Apfides, which goes

goes through the Center of the Earth, goes forwards twice, and backwards twice.

4263. *The Apsides of the Moon go forward when the Moon is in the Sy-*
 * 631. 4232. *zygies* *, or rather whilst the Moon moves between the Points,
 † 4247. which are 54 Deg. 44 Min. distant from them †. *In the Quadra-*
 4264. *tures, and between the Points distant from them 35 Deg. 16 Min.*
 * 632. 4223. *The Apsides go backwards, that is move in Antecedentia*.*

4265. The Forces upon which the *Progress* and *Regress* of the *Apsides* depend, are the Forces which disturb the Motion of the Moon, which have been before explained; therefore since the disturbing Force in the Syzygies, is double the disturbing Force, in the Quadratures *; the Progress, which also has Place in a longer Arc †, considering one intire Revolution of the Moon, exceeds the Regress, *cæteris paribus*.

4266. In a Circle whose Center is in the Center of the Forces, the Diminution of the Force, in receding from the Center, produces no Effect; because in such a Line the Body does not recede from the Center; therefore the Effect of this Diminution is so much the greater, as the Curve described by the Body differs more from such a Circle.

4267. In an elliptic Orbit, one of whose Foci coincides with the Center of the Forces, the Curvature in the *Apsides* differs most of all from such a Circle, and the Effect of the Diminution of the Force, in receding from the Center of the Forces, is the greatest of all.

4268. If this Orbit is but a little excentric at the Ends of the lesser Axis, the Curvature of the Circle above-mentioned differs little from the Curvature of the Ellipse, in respect of the Forces, and the Effect of the Diminution is the least of all.

4269. The Progress and Regress of the *Apsides* depend upon the Proportion, according to which the Force of Gravity decreases, receding from the Center of the Earth *; it is therefore the Effect of the Diminution of the central Force.

4270. This Motion of the *Apsides*, which we have explained, under-
 Plate 127. goes several Changes; the *Apsides* go forward fastest of all in a Re-
 Fig. 2. *volution of the Moon, supposing the Line of the Apsides in the Sy-*
 * 4263. 4269. *zygies* *; and in that very Case, they go back the slowest of all in
 4267. *the same Revolution* †, because, by reason of the small Excentricity
 † 4264. 4269. of the Moon, the Quadratures are but very little distant from the
 4268. Ends of the lesser Axis of the Orbit.

4271. Supposing the Line of the *Apsides* to be in the Quadratures, the
 Pl. 127. F. 3. *Apsides* are carried in Consequentia, the least of all in the Syzygies *;
 * 4263. 4269. but they return the swiftest in the Quadratures †; and in this
 4268. Case,
 † 4264. 4269. Case,

Case, in one intire Revolution of the Moon, the Regress exceeds the Progress.

Whilst the Earth is carried along in it's Orbit, the Line of the Apfides does fucceffively go through all Situations in respect of the Sun ; wherefore, *considering a great many Revolutions of the Moon taken together, the Apfides go forwards* * ; and it is plain from Ob-
servations, that in the Space of about eight Years, the Line of the Apfides performs one intire Revolution. 4272.
4265.

We have also said that the Excentricity of the Orbit is not constant.

The Excentricity of a Body is increased, if the central Force, the Diminution being continued, decreases faster than before, whilst the Body is carried from the lower to the upper Apfis ; for then it is every Moment less attracted, than if the Force decreased less, and therefore it recedes the more. The Excentricity of the Orbit is also thereby increased, in the same Case, in the Motion from the upper to the lower Apfis, because in this Case, coming towards the Center, the Force increases so much the faster, as the Body descends more towards the Center ; so that in each Case, the Difference, between the greatest and least Distance from the Center of the Forces, may become greater, and the Excentricity be thereby in-
creased. By the same Reasoning it appears, that *the Excentricity is diminished, when the central Force decreases more slowly than before in the Recests from the Center.* 4273.
4274.

Applying this to the Moon's Motion, *it appears, that the Excen- tricity of the Orbit, every Revolution, undergoes various Changes :* That it is increased when the Moon goes through the Syzygies *, * 4232. 4273. and diminished when it is in the Quadratures † : *That Excentri- † 4223. 4274. city is the greatest of all when the Line of the Apfides is in the Syzygies ;* 4276. because in one intire Revolution, the Cause which moves the Ex- centricity is the greatest of all ; and that which diminishes it, the least of all, because the Forces in the Apfides, being compared, do decrease faster than in an inverse Ratio of the Square of the Di- stance *, whence this Addition follows †, which prevails in this * 4232. † 4273. Position ‡ : But *the Orbit is the least excentric of all, when the Line ‡ 4267. of the Apfides is in the Quadratures, the Diminution of the Excen- tricity prevailing* *. * 4223. 4274.

We have said that the Moon moves in a Plane inclined to the Plane of the Ecliptic ; that the Line of the Nodes is carried round *in Antecedentia* * ; and that the Inclination of the Orbit is not con-
stant † ; these Effects are also deduced from the Action of the Sun †
upon the Moon. 4277.
3743.
3742.
By

By reason of the small Inclination of the Moon's Orbit, the Forces which we have hitherto considered acting in the Plane of the Ecliptic, not regarding the Inclination of the Orbit, may (without any sensible Error) be referred to the Plane of the Orbit; and the Moon in it is subject to the Motions before explained: But

4278. *there is a Force which removes the Moon from the Plane of the Orbit* *;
 * 4260. so that we must conceive that Plane to be agitated, otherwise the Moon would go out of the Orbit.

4279. Let the Moon be at F; if we attend to what has been said above
 Plate 127. concerning the Action of the Sun *, it is plain, that the Plane of
 Fig. 1. the Parallelogram F H M I goes through the Line T S, which joins
 * 4233. the Centers of the Earth and Sun; and therefore it is in the Plane
 of the Ecliptic; so that the Point N, to which is directed the Force
 disturbing F N, on account of the Action of the Sun, is in that
 Plane.

4280. Let the same Force be represented by F I; at F let F R be raised
 Pl. 127. perpendicular to the Plane of the Orbit; and imagine the Paralle-
 Fig. 4. logram F R I i, whose Side F i is in the Plane of the Orbit, and
 whose Diagonal is F I; the disturbing Force along F I, is resolved
 into two, in the Directions F R and F i, which these Lines repre-
 * 360. sent*, and of which this last acts in the Plane of the Orbit: So that
 we must refer to this what relates to the disturbing Force, of which
 we have treated in N^o 4233; for the Lines F i and F I scarce dif-
 fer, and the Plane of the Parallelogram F R I i is perpendicular to
 the Plane of the Moon's Orbit.

4281. The Line F R must be determined, which represents the Force
 that acts perpendicular to the Plane of the Orbit, and removes the
 Moon from that Plane; now the Ratio of the Line F R or I i,
 to the Radius E T, is the Ratio of the disturbing Force, which is
 * 6337. spoken of here, to the Increase of Gravity in the Quadratures *.

4282. In the Case of this Figure, in which the Line of Nodes N n is
 in the Quadratures, we find out F R; because I T, which is N T
 of Fig. 1. is given, and because I T is to I i, or F R, as the Radius
 * 4243. to the Sine of the Inclination of the Orbit *.

4283. But in every Case the Force must be determined which drives
 the Moon out of the Plane; let us therefore suppose the Line of
 Nodes carried to the Situation M m, whereby, every Thing else
 remaining as before I i is changed. To M m continued, if Need be
 let i X and I X be drawn perpendicular, which make an Angle
 equal to the Inclination of the Plane of the Orbit.

The Ratio between $E T$ and $I i$, that is *the Ratio between the Addition of Gravity in the Quadratures, and the Force*, which we seek, *which removes the Moon out of the Plane of it's Orbit*, is compounded of the Ratios of the Line $E T$ to $T I$, of the Line $F I$ to $I X$, and lastly of the Line $I X$ to $I i$. The first is the Ratio between the Radius, and three Times the Sine of the Distance of the Moon from the Quadrature *; the second is the Ratio of the Radius to the Sine of * 4284.
the Angle $I T X$, that is, of the Distance of the Node from the Syzygy; lastly, the third is the Ratio of the Radius to the Sine of the Inclination of the Orbit: And the Ratio, compounded of these, *is the Ratio of the Cube of the Radius to three times the Product, of the Sines of the Distances of the Moon from the Quadrature, and of the Node from the Syzygy, as also of the Inclination of the Plane.* To this Force also is to be referred N° 4249. 4243.

This Force vanishes in the Quadratures, because the Point I coincides with the Point T , which is the Center of the Earth, and the Line $I i$ vanishes; the Lines $F I$ and $F i$ concurring in the Plane of the Orbit, which also follows from the Computation above-mentioned *; the Sine of the Distance of the Moon from the * 4284.
Quadrature vanishing, and consequently, the whole Product which is multiplied by that Sine.

That same Product vanishes also, and with it *the Force* which 4286.
it represents, when the Sine of the Distance of the Node from Plate 127.
the Syzygy *vanishes*, that is, *supposing the Line of the Nodes in the Sy-* Fig. 5.
zygies: It is also deduced from this, that the Line of Nodes $N n$ continued, goes through the Sun; wherefore the Sun is in the Plane of the Orbit itself, and therefore cannot draw the Moon but in that Plane.

The Force also which we examine, is increased as the Moon advances towards the Syzygy, and as the Node recedes from it *. 4287.
* 4284.

Let $P p$ be the Plane of the Ecliptic, $P A$ the Orbit of the Moon; 4288.
when the Moon is come to A , that is, is receded a little from the Plate 127.
Node, it is removed out of the Plane of the Orbit, and in the se- Fig. 6.
cond Moment is not carried along $A B$, (the Continuation of the Orbit $P A$) but along $A b$; because it comes towards the Plane of the Ecliptic along $B b$; therefore it is moved as if it came from a more distant Node p . Whence it appears, that *the Nodes go back-* 4289.
ward, whilst the Moon moves in it's Orbit, as long as it recedes from the Node: The Nodes also go back whilst the Moon is going to the opposite Node; because as the Moon is continually driven out of it's Orbit towards the Plane of the Ecliptick, it is continually

directed to a Point less distant, and comes sooner to the Node, than if, not being agitated by such a Motion, it had continued in Motion with the same Celerity.

4290. *Considering one intire Revolution of the Moon, cæteris paribus, the Nodes move in Antecedentia swiftest of all, when the Moon is in the Syzygies*, then slower and slower, till they are at Rest when the Moon is in the Quadratures†.*

* 4287.

† 4285.

4291. Whilst the Earth is carried round the Sun (even when we don't attend to the abovementioned Motion of the Nodes) the Line of Nodes does successively acquire all possible Situations in respect of the Sun; and every Year goes twice through the Syzygies, and twice through the Quadratures.

4292. *If now we consider several Revolutions of the Moon, the Nodes in one whole Revolution go back very fast, the Nodes being in the Quadratures* ; then slower, till they come to Rest, when the Line of*

* 4287.

† 4286. *Nodes is in the Syzygies†.*

4293. By the same Force with which the Nodes are moved, the Inclination of the Orbit is also changed; it is increased as the Moon recedes from the Node; and diminished as it comes to the Node.

4294. For the Angle bpL is less than the Angle APL , and for the same Cause it is continually diminished, and the Inclination becomes greater; but when the Moon is come to the greatest Distance from the Plane of the Ecliptic, and is going towards the opposite Node, the Direction of the Moon is continually inflected towards the Plane of the Ecliptic, and less inclined to it than if it continued in Motion in it's Orbit: Let Nnn be the Plane of the Ecliptic; the Curve, Nn the Orbit of the Moon; by the Force whereby the Moon is continually removed out of it, the Way of the Moon is changed, and it goes in the Curve Nn , which is more inclined to Nnn at N than at n ; so that we must conceive the Inclination of the Plane of the Orbit to be twice changed*, whilst the Moon moves from one Node to the other; therefore this happens four times in each Revolution of the Moon, it is twice diminished, and twice again increased.

* 4278.

4295.

4296. *Supposing the Nodes Nn , to be in the Quadratures, the Forces which in one Revolution increase the Inclination and diminish it, are equal to one another; for by reason of the equal Distance of each Node from the Syzygies, the Forces that change the Inclination at ND and nE are equal to the Forces in the correspondent Points*

Pl. 127.
Fig. 4.

* 4284. *in the Arcs Dn and EN *; by the former the Inclination is in-*

† 4293. *creased, by the latter it is diminished†; the Diminution of the Angle*

Angle of Inclination, on account of the first, is restored by the Action of the second, and here it is *not changed*. In the Motion abovementioned * of the Line of Nodes in respect to the Sun, which * 4291. depends upon the parallel Situation of this Line, the Node N is carried to the Syzygy E. When (for Ex.) the Line of Nodes is come to the Situation Mm, the Moon in it's Recess from the Nodes goes through the Quadratures Nn, in which the Force which changes the Inclination vanishes *, and near which, it is the least * 4285. of all †: But in coming towards the Nodes, the Moon is every † 4284. where distant from the Quadratures, and a greater Force acts upon it *; therefore *considering one intire Revolution*, the Increase of the * 4284. Angle of Inclination exceeds the Diminution †; that is, that Angle 4297. is increased, or, which is the same, *the Inclination is diminished*; † 4293. which obtains every where in the Motion of the Nodes from the Quadratures to the Syzygies.

When the Nodes are come to the Syzygies, the Inclination of the 4298. Plane of the Orbit is the least of all; for in the Motion of the Nodes 4299. from the Syzygies to the Quadratures, the Plane of the Orbit is continually more and more inclined; for in that Case as the Moon goes to the Node, it passes through the Quadratures; in it's Recess from them the Moon is distant from the Quadratures, and in one whole Revolution of the Moon the Force which increases the Inclination * exceeds that which diminishes it †; therefore *the Inclination is increased*; and it is greatest of all when the Nodes are in the † 4300. Quadratures, where the Diminution of the Angle made by the Plane of the Orbit with the Plane of the Ecliptic is determined *. * 4296.

All the Errors in the Moon's Motion, that we have explained, 4301. are something greater in the Conjunction than in the Opposition †. † 4229.

All the disturbing Forces are determined by discovering their 4302. Ratio to the Addition of Gravity in the Quadratures *, for * 4245. 4247. 4284. which Reason they all undergo the same Changes as that Addition does; that is, they are *inversly as the Cube of the Distance of the Sun from the Earth* †, which when it remains the same, they are as † 4222. the Distance of the Moon from the Earth *. Considering all the di- * 4220. sturbing Forces together, the Diminution of Gravity prevails †; which 4303. follows immediately from the Progress of the Apfides †; for it ap- † 4230. pears from thence, that considering several Revolutions together, † 3743. 4272. the Effect of the Diminution of Gravity exceeds the Effect of the Increase of it *. * 630. 631.

4304. Therefore *the Motion of the Moon being considered in general, the Gravity of the Moon towards the Earth is diminished, coming near*
 * 4303. 4302. *the Sun* * ; therefore when it is less attracted by the Earth, it recedes more from it than it would recede, if there was no such Diminution of Gravity ; therefore in that Case the Moon's Distance
 4305. is increased, as also *the periodical Time* * ; and that Time is the
 * 582. *greatest, as also the Distance of the Moon (cæteris paribus) the greatest, when the Earth is in the Perihelion* ‡, because then it is least distant from the Sun.

C H A P. XVII.

Concerning the Figures of the Planets.

4306. **I**F we consider the Figures of the Planets, we shall find that they have such Figures which follow from these very Laws by which the System is governed ; which is very agreeable to that admirable Order which we observe every where, that no Forces
 4307. act upon the Planets to destroy them ; that is, that *the Figure of a Planet, whether it be a primary or a secondary Planet, is such as it would acquire, if it wholly consisted of fluid Matter* ; which agrees with the Phænomena.
4308. Whence it follows, that *all the primary and secondary Planets are spherical* ; for they consist of a Matter whose Particles gravitate
 * 4047. 4048. towards one another * ; from which mutual Attraction a spherical Figure is generated in the same Manner, as a Drop becomes round from another sort of Attraction of the Parts ‡.
- ‡ 76.
 4309. *This spherical Figure of the Planets is not changed from their Motion round the Sun, or from the Motion of the secondary Planets about their primary ones* ; because all the Particles are carried by the same Motion : But this Figure undergoes some Change by the Motion round the Axis, and so much the greater as the Motion is swifter.
4310. For by the centrifugal Force *Bodies are under the Æquator* ; therefore as we demonstrate in our second Scholium, a Planet is every where higher under the Æquator than the Poles ;
 4311. *and from it's Motion round it's Axis, it acquires the Figure of a Spheroid depressed at the Poles* ; for the Height is continually diminished as you go towards the Pole ; because the centrifugal Force is diminished, by reason of the Distance from the Axis diminished *.
- * 607.

Chap. 17. of Natural Philosophy.

365

If what has been demonstrated be compared with the Phænomena, it will appear why all the Bodies in our System are spherical *; but that this Figure is not exact, but a little changed by their Motion round their Axis †, though this cannot be observed † in most of them, may be deduced from Observations made upon Jupiter and the Earth. Astronomers have observed, that the Axis of Jupiter is shorter than it's æquatorial Diameter; although this Planet be the greatest of all the Planets, it is moved the swiftest about it's Axis *; and therefore this Difference may be observed. *

4312.

3690.

4310.

4313.

* 3731.

4314.

† 4322.

The Elevation of the Earth at the Æquator is determined †, although perhaps to the Inhabitants of the other Planets, if there are any, it may not be more sensible than the Depression of the Poles of Mars to us, which is so small that we cannot perceive it.

Let us suppose the Earth fluid, and it will acquire the abovementioned sphæroidal Figure*; if it consists of heterogeneous Matter, and it's Parts are more dense, receding from the Center, but equally dense at the same Distance from it, there will not be an Æquilibrium, except the Earth be more depressed under the Pole, than if it was homogeneous, as we demonstrate in the 2d Scholium.

4315.

* 4311.

Now if we conceive the Parts to cohere towards the Center, the Situation of the other Parts cannot be changed by that Means, neither will it be changed, if in some Places the Part cohere with one another quite to the Surface, as that really is the Case. Therefore the Surface of the Sea has a Figure depressed at the Poles.

4316.

Since therefore the Shores every where are raised but a little above the Surface of the Sea, which contains the Earth, it follows that the Earth is doubtless of the same Figure as the Sea.

As to what relates to the Figure itself, it can be only determined from immediate Measures and actual Observations; as we shall shew in the Scholia, in which we shall demonstrate what I shall now say.

4317.

Let e P E be the half of the Section of the Earth through the Meridian; C the Center; P the Pole; E e the æquatorial Diameter.

4318.

Tab. 126.

Fig. 9.

This æquatorial Diameter contains 3399474 Rbynland Perches.

4319.

The Axis of the Earth = 3380460.

4320.

Therefore the mean Diameter contains 3389940.

4321.

The Æquator is raised 9534 Perches.

4322.

The Ratio between the Axis and the Diameter is that between 177,3 and 178,3.

4323.

The

4324. The Surface of the Sea must be so fitted to those, as to be perpendicular to the Direction of heavy Bodies * ; and the Tangent I F, which agrees with that Surface in the Point I, determines the horizontal Plane †. But it is plain that a Line perpendicular to the Tangent, which shews *the Direction of heavy Bodies*, as I B, *cannot always tend to the Center of the Earth*.
4325. † 3909. Yet this Line determines the Height of the Pole ; for that Height is equal to the Angle which I F makes with P C *, or I D, which we suppose parallel to the Axis, that is perpendicular to e E ; this Angle is D I F, to which I B D is equal.
4326. * 3947. If, having drawn *i b* perpendicular to the Surface at *i*, the Angle *i b* D is greater than the Angle I B D one Degree, the Points I and *i* will also differ one Degree in Latitude ; and the Arc I *i* is of one Degree in the Meridian. If we conceive the whole Arc P I E thus divided into 90 Degrees, these *won't be equal to one another* ; for every oval Figure is the most convex at the Extremities of it's greater Axis, and the least so at the Ends of it's lesser Axis ; whence it follows that the Concourse of the Lines I B, *i b*, that is the Point A, is more removed from the Surface the more I comes towards the Pole ; for A is the Center of a Circle, which coincides with the Arc I *i*, and the Radius of the Circle is so much the greater, as the Surface is less curve ; but as I A increases, the Arc I *i* does also increase. Therefore *the Degrees increase as you go towards the Pole, and the Degree at the Pole is the greatest, and that at the Æquator the least*.
4327. 4328. The greatest Degree contains 29833,4 Rhymland Perches ; and the least 29334,15.
4329. 4330. Therefore the mean Degree is of 29583,77 Perches. This Degree scarce differs from that whose Latitude in it's middle Point is 45 Degrees.
4331. 4332. Between the least and the greatest Degree, there is a Ratio of 59,75 to 58,75 ; nearly as 60 to 59.
4333. 4334. Gravity also differs in different Latitudes, it is the least under the Æquator *, and the greatest under the Pole, and these Gravities are to one another as 201,5 to 202,5.
- * 4310. 4335. The Length of a Pendulum which performs it's Vibrations in a Second, was exactly measured by the famous Monf. Mairan, who found it to be 440,57 Lines of the Royal Paris Foot. The Height of the Pole is 48 Deg. 50'.
4336. The Pendulum being carried to Lapland, Observations were made there in the Latitude of 66 Deg. 48', by which it appeared that this Pendulum had performed 86217,5 Vibrations in the same Time

Time that at *Paris* it had only performed 86158,4 Vibrations, whence it appeared that the Gravities in those Places were to one another as 729,6 to 728,6 *; how the Gravities of all the Places * 4328. of the Earth may be compared by this Determination, will be seen in the 4th Scholium; and these are as the Lengths of Pendulums performing their Vibrations in equal Times *. * 431.

The Length of a Pendulum, which performs its Vibration in a Second, is under the *Æquator* 455,14 Lines of the *Rhynland* Foot, and 456,42 Lines of the same Foot at *Paris*; at the Latitude of 86 Deg. 48' in the Village of *Pello* in *Lapland* 457,08 Lines of the same Foot; and at last under the Pole 457,40 Lines. 4336.

If Bodies fall freely, we know what Space they go through in 1" *. And it is in the four Places we have mentioned, if we * 4337. make use of the *Rhynland* Measure, of the following Feet, viz. 415.374. 15,597. 15,641; 15,663; 15,674.

A Body falling by a mean Gravity, which differs equally from the greatest and the least, goes through 15,635 Feet, in". How to determine the mean Gravity, when it is to be compared with that Gravity with which a Body removed beyond the Atmosphere, comes towards the Earth, has been before shewn *. * 4338. * 4080.

SCHOLIUM I.

Concerning some Properties of the Ellipse.

LET *e* P*E* be a Semi-ellipse; *E* *e* it's greater Axis: *CP* it's lesser Semi-axis; *CD* any Absciss; *DI* an Ordinate answering to it; *e* *e* *E* a Semi-circle whose Diameter is *e* *E*. 4339. Plate 172. Fig. 7.

In the Ellipse we have

$$ED \times De = DK^2 *, DI^2 : : CE^2 = Ce^2, CP^2 \dagger.$$

When the Squares are proportional, the Roots also are proportional.

Therefore *DK*, *DI* : : *Ce*, *CP*.

If therefore a Circle be described, whose Diameter is the lesser Axis of the Ellipse, and *HI* be drawn, an ordinate to this Axis, cutting the Circle at *i*, we demonstrate in the same manner this Proportion to be given *Hi*, *HI* : : *CF*, *CE*. 4341. 4342. 4343.

The other Things regard the Computations, and must be treated algebraically.

We put therefore *z* = *CE*, the half Axis of the greater Ellipse.

u = *CP*, the half Axis of the least.

x = *CD* = *HI*, any Absciss.

y = *DI*, answering to the Ordinate.

4344.
Plate 126.
Fig. 9.

Besides

4345. Besides let IF be the Tangent of the Ellipse at I, and IB perpendicular to the Ellipse, and therefore to the Tangent, in the same Point I; the Point of Concourse of that Perpendicular with the next, which is at an infinitely small Distance, that is AI, is the Radius of the Convexity of the Ellipse at I, which we call $r = AI$.

4347. The Angle IBD, which this Perpendicular AI makes with the Axis
* 8 El. 6. eE , is equal to the Angle DIF *.

4348. Let s be the Secant of that Angle;
 t its Tangent, supposing the Radius 1.

* 47 El. 1. Therefore $tt + 1 = ss$ *; and $ss - tt$ will be $= 1$.

4350. Let us further put $zz, uu :: 1, a$;

4351. Therefore $a = \frac{uu}{zz}$.

4352. And az is the Parameter of the greater Axis.
These being thus put, we discover the Value of the remaining Lines.

4353. $sy = IF$; because $1, s :: y, IF$.

4354. $ty = DF$; because $1, t :: y, DF$.

4355. $\frac{sy}{t} = IB$; because $t, 1 :: IF (sy), IB$.

4356. $\frac{y}{t} = DB$; because $t, 1 :: y, DB$.

4457. In the Ellipse it is as we have seen before *.

* 4340. $z - x \times z + x = zz - xx, yy :: zz, uu :: 1, a$ †.

† 4350. We have also $\div \div CD, CE, CF$ *; that is,
4358. $\div \div x, z, x \div ty$, and $zz = xx + xty$, or $zz - xx = xty$.

* La Hire, sect. con. lib. 3. prop. 8. And the foregoing Proportion † is chang'd into this,

† 4357. $1 . a :: xty, yy :: xt, y$.

4359. Therefore $y = atx$, or $x = \frac{y}{at}$.

4360. And $ax = \frac{y}{t} = DB$ *.

† 4358. If in the Equation $zz = xx + xty$ †, for x we substitute atx *, we have

* 4359. $zz = xx + attxx$; that is, $zz = xx \times \overline{1 + att}$; and $z = x \times \overline{1 + att}^{\frac{1}{2}}$

4361. Whence we deduce $xx = \frac{zz}{1 + att}$; and $x = \frac{z}{\overline{1 + att}^{\frac{1}{2}}}$.

4363. And therefore $y = \frac{atz}{\overline{1 + att}^{\frac{1}{2}}}$ *.

4364. Between the Lines DC, DB, there is a constant Ratio of zz to uu ,
* 4350. that is, 1, to a *; for they are x and ax †.

* 4344. 4360. By Conversion $CD, CB :: 1, 1 - a :: Cd, Cb$.

4365. Whence it follows $Dd = gI, Bb :: 1, 1 - a$.

4366. We have also $GI, gI :: BF, DF$, because of the Figures $IGig$, $FBID$, which are similar.

Therefore

Therefore joining the Ratios

$$GI, Bb :: BF, DF - a DF.$$

Because of the similar Triangles AGI, ABb,

$$GI, Bb :: AI, AB :: BF, DF - a DF *.$$

By converting and inverting, IB, AI :: BD + a DF, BF = BD + DF.

Algebraically $\frac{sy}{t} *$, $r + :$ $\frac{y}{t} * + a ty +$, $\frac{y}{t} + ty$. That is, dividing the Terms of the last Ratio by y , and multiplying them by t ,

$$\frac{sy}{t}, r :: 1 + att, 1 + tt = ss \parallel.$$

Whence $r = \frac{s^3 y}{t + at^3} = \frac{s^3 ax}{1 + att} * = \frac{s^3 a^2}{1 + att}^{\frac{1}{2}} +.$

And whence again $z = \frac{r \times \sqrt{1 + att}}{s^3 a}$ and $zz = \frac{rr \times \sqrt{1 + att^3}}{s^6 aa}$.

Having extracted the Cube Root from each Member of the last Æquation, you have

$$z^{\frac{2}{3}} = \frac{r^{\frac{2}{3}} + r^{\frac{2}{3}} att}{ssa^{\frac{2}{3}}} = \frac{r^{\frac{2}{3}} + r^{\frac{2}{3}} att}{a^{\frac{2}{3}} + a^{\frac{2}{3}} tt} *.$$

Whence is deduced $tt = \frac{r^{\frac{2}{3}} - a^{\frac{2}{3}} z^{\frac{2}{3}}}{a^{\frac{2}{3}} z^{\frac{2}{3}} - ar^{\frac{2}{3}}}.$

By the Help of the Æquations, which we have hitherto drawn from the Nature of the Ellipse, we may discover several Lines in a given Ellipse: but in all of them we suppose the Form of the Ellipse, or the Ratio between the Axes to be known; but if a be sought, and the Convexity of the Figure be given in two Points, for which also is given the Inclination of the Tangent to the Axis, by the following Method we shall investigate an Æquation, which shews the Value of a .

r, s , and t are given; we suppose r, s , and t to signify the same Quantities given for another Point. Then we have

$$zz = \frac{rr \times \sqrt{1 + att^3}}{s^6 aa} = \frac{rr \times \sqrt{1 + att^3}}{S^6 aa} *.$$

Whence multiplying the Æquation by $s^6 S^6 aa$, and extracting the Cube Root from each Member, we deduce the Æquation.

$$r^{\frac{2}{3}} SS + r^{\frac{2}{3}} a tt SS = r^{\frac{2}{3}} ss + r^{\frac{2}{3}} att ss.$$

Which gives $a = \frac{r^{\frac{2}{3}} ss - r^{\frac{2}{3}} SS}{r^{\frac{2}{3}} tt SS - r^{\frac{2}{3}} tt ss}.$

Each of the Æquations expresses the Theorem, which is made use of in the Computations concerning the Figure and Magnitude of the Earth, and

does immediately shew what Operations are to be gone through for the Solutions of particular Questions.

S C H O L I U M II.

Concerning the Figures of the Planets in general.

4375.
* 4311.

WE have said, that spherical Planets made of fluid Matter, change their Figure, by their Revolution about their Axis*; we shall now consider this Change, and immediately apply our Reasonings to the Earth.

Pl. 126.F.8.

4376.

Let P be the Pole; C the Center; Ee the Diameter of the $\text{\AA}$ equator; we conceive the Earth fluid and homogeneous, and that it turns about it's Axis. We suppose that it has acquired the Figure $ePIE$, into whose Nature we are first of all to inquire. If some of the Parts cohere, the Fluid will press them in the same manner as before the Cohesion, and the Figure will not be changed; neither can it be changed, although in some Places the Parts cohere from the Center quite to the Surface; therefore the Surface of the Sea would acquire the same Figure then, that it would do if the Earth was wholly fluid, as we have already taught*.

* 3315.
4377.

Now let us suppose Tubes to be placed as PC , HI , CE , which communicate; the Fluid will dispose itself in them, at those Heights in P , I , E , at which it was before*; therefore the right Columns CP , CE , will be in $\text{\AA}$ equilibrio; as also the right Column HP , with the oblique one HI .

4378.
Pl. 126.
Fig. 7.

The Earth being at rest, the Columns CP , CE are equal, as also CP , CF , then the third HI , which is in the same Case as Hi , is equal to the Co-sine of the Altitude of the Pole.

4379.

Let us suppose Gravity on the Surface of the Earth to be represented by the Radius PC or iC , or FC ; then the Gravity in every Point will be represented by the Distance of those Points from the Center*; so Gravity at L is as LC , and at l as lC .

* 4089.

4380.
* 319.

If we resolve the Gravity acting in the Direction iC , into two Pressures along id and iH , they will be proportionable to those Lines*. In the same manner if the Gravity LC of the Point L be resolved into two Pressions along Ll , and LH , they will also be proportionable to those Lines.

Whence it follows, because iH and dC are equal, as also LH and lC , if we reason in the same manner concerning all the Points of the Line iH , that the whole Pressure of the Column iH , against the Point H , is equal to the Weight of the Column dC .

4381.

Now if we suppose the Earth to turn about it's Axis, the Fluid will become lighter in the Tube CE , and Gravity will be diminished along the whole Length of the Tube according to the same Ratio; for that, and the

* 4089. 607. centrifugal Force are every where as the Distance from the Center*; therefore

therefore in Proportion of that Diminution of Gravity the Column C E is extended, for it will not be in *Æquilibrium* with the Fluid in the Tube P C, unless the Height of that, be to the Height of this; as the Gravity in any Point of this, to the Gravity in a correspondent Point of that. For then the Column E C presses, as much as this pressed before when it had the Height C F; and because Gravity is always unchanged in it's Ratio of the Distance from the Center, the Part C D, which presses, as much as C d pressed, is had by this Proportion:

$$C d, C D : : C F, C E.$$

The Earth being at rest, the single Points of that Part C d of the Column C E, press as much, as, in that Case, the correspondent Points of the Column i H, do; but if the Earth turns about it's Axis, the Column i H is moved in the same manner as C d; and the Pressure of this in each Point is changed in the same manner as the Pressure of the other; therefore, that after the Pressure has been diminished by the centrifugal Force; this may become equal to the Pressure that it had before, it must extend itself to I, so that H I may become equal to C D; and the like Demonstration may be applied to all the Lines as H I.

When the Figure of the Earth is changed by its turning about it's Axis, the Distance C P is diminished, but the Demonstration is not changed; for C P remaining the same, we may suppose Matter to be added outwardly, as much as is wanting to restore the *Æquilibrium*.

We have therefore this Property of the acquired Figure, $H i = C d$ is to $H I = C D$, as C F is to C E*; which is the Property of the Ellipse†. *

We must observe besides, that the Figure must necessarily be so changed, that the Direction of Gravity may be perpendicular to the Surface, otherwise, in respect of fluid Substances, the Figure would again be changed by their flowing; therefore the Earth can only acquire an elliptic Figure in those Cases, in which, supposing it to be such, the Direction of Gravity is perpendicular to the Surface, which only obtains, when the Circle differs but little from an Ellipse, which happens in the Earth.

We have supposed Gravity at i to be represented by i C*, whence we have deduced the Pressure along i H, to be expressed by that Line itself; and therefore that i I represented the Diminution of Pressure from the Revolution; for the intire Pressure must be increased by that Quantity, that the *Æquilibrium* may be restored, when it is diminished by the Revolution about the Axis.

The Particle at i is then drawn along i C, and i I, by Forces proportionable to those Lines, and drawing I c, parallel to i C, the Particle is driven along i c, by an Action proportional to that Line*.

By these Actions, the Particles are pressed every where between i and I, and the Direction of Gravity in I is parallel to i c, and also proportional to that Line, as long as i I is small; if the Earth remaining spherical, there should be given a Particle at I separated from the Earth, the Change of the Direction of Gravity on account of the centrifugal Force

4382.

4383.

4384.

4385.

4382.

4342.

4386.

4387.

4388.

* 318.

4389.

would be something less, because the Direction of Gravity itself would not be iC or Ic , but IC ; now Matter added increases the Deflection, and the Direction of Gravity IG , as to Sense is parallel to ic ; and therefore as to Sense it is also perpendicular to the Curve at I , as I shall deduce from what has been before demonstrated.

4390. We consider the Figure differing but little from a Circle, therefore Cc and tG must be small, in respect of DC ; Cc and cG are also equal as to Sense, this last scarce wanting any thing of Ii ; therefore DC , Dc , DG are in continued Proportion; at least they may be looked upon as such without any sensible Error

4391. Since the following are equal IH , DC , as also Ii , Cc ; iH will also be equal to Dc ;

* 4343. But CE , $CF = CP :: IH$, iH *.
Therefore CE , $CP :: DC$, Dc .

† 4390. And CE^2 , $CP^2 :: DC^2$, $Dc^2 :: DC$, DG †.

* 4364. Whence it follows that IG is perpendicular to the Ellipse *, which was to be demonstrated.

4392. From what has been demonstrated in N° 4388. it follows that Gravity is the greatest of all under the Pole, and that it is continually diminished receding from the Pole, and the least of all under the Æquator, as we have taught *.

* 4333. Now to determine the Law of this Diminution, let us conceive the Arc cn to be described with the Center i , through the Point c ; Cn expresses the Diminution in Question; for Ci , equal to CP , shews the Gravity under the Pole, and ic the changed Gravity, which we want.

4394. The Diminution of Gravity under the Æquator is as FE , when the
* 4381. Gravity under the Pole is expressed by CP , as we have seen *; therefore the Diminution under the Æquator is to the Diminution at I , as FE to Cn ; that is in the Ratio compounded of FE to Ii , and of that to Cn .

* 4385. The first of these Ratios, namely that of FE to Ii , is that which is given between CF , or Ci , and iH *. The second which is given between Ii and Cn , is the same with the first; for Ii is equal to Cc , and Cc is to Cn , as Ci to iH , by reason of the similar Triangles CiH and Ccn ; because the little Arc cn may be considered as a right Line perpendicular to Ci . Therefore the Ratio between FE and Cn is the duplicate Ratio of that which is given between Ci and iH ; and therefore
4395. the Diminution of Gravity is every where as the Square of the Line iH , that is, as the Square of the Co-sine of the Latitude of the Place.

4396. Gravity is increased receding from the Æquator, till it is the greatest of all under the Pole; and the Augmentation every where, is the Difference between the greatest Diminution, namely that which has place under the Æquator, and that which obtains in the Place in Question: therefore in I that Augmentation is, as the Difference of the Squares Ci
* 41. El. 1. and $H i$, which is equal to the Square of HC *, or id ; that is, the Increase of Gravity, in any Place, is as the Square of the Sine of the Latitude of the Place.
I have

I have considered no other Change of Figure but that arising from the centrifugal Force, but there is another Change of Figure joined with it; for since Gravity tends to every Particle of Matter, the respective Situation of those Particles being changed, the Gravity of the Particles compounding the Planet is so changed, that even setting aside the centrifugal Force, Bodies are lighter under the *Æquator* than at the Poles*. Whence * it follows, that a Planet is more depressed at the Poles, when it revolves about it's Axis, than what follows from the centrifugal Force alone.

4398.

4389.

In all these Cases we have supposed the Planet homogeneous, and investigating the Thing farther, what would be the Figure of it, that is, what would be the Ratio between the Axis and the *æquatorial* Diameter, in such an Hypothesis; but the Measures taken in several Places of the Earth do not agree with such a Figure.

4399.

Therefore we will examine how the Figure of a Planet may be differently varied by it's Motion round it's Axis, according to it's different Constitution, though, setting aside the said Motion, we conceive it to be fluid and spherical, but of different Density, at different Distances from the Center; but we must return to the Case which we have examined.

4400.

We conceive a Planet spherical, at rest, of homogeneous and fluid Matter. A Column as CE, is drawn towards the Center by Gravity; if the Planet turns about it's Axis, that Gravity is diminished by the centrifugal Force; the Figure of the Planet is then changed, and depressed at the Poles as we have shewn *. But it appears clearly that this Change * of Figure depends upon the Ratio which is between the centrifugal Force and Gravity; which we also refer to the second Cause of Change, which follows from this first †.

4401.

4381.

* 4398.

The Figure of a Planet is more changed, and more raised under the Æquator, and therefore depressed under the Poles, if other things remaining as they are, the centrifugal Force be increased; for this Force diminishes the Gravity, and is the Cause of extending the Column CE.

4402.

Neither is it less evident, that *the spherical Figure is also the more changed, if the centrifugal Force remaining, the Gravities of the Columns CP, CE are lessened*; if for Ex. the Gravity of the Column CE be diminish'd one hundredth Part of the centrifugal Force, the Height CE will exceed CP by such a Part; and by reducing the Gravity of the Columns to half, the centrifugal Force, which we suppose to remain the same, which was the hundredth Part of the former Gravity, is now equal to two hundredth Parts of the last Gravity, and the Height CE will exceed the Height CP one 50th Part, and therefore will more change the Figure.

4403.

Let us again conceive the Planet spherical, made of fluid Matter, or at least soft enough, of the same Density at equal Distances from the Center, but which grows continually denser receding from it. If such a Planet revolves round it's Axis, the Figure will be changed, and what we have demonstrated of the *Æquilibrium* of the Columns PC, CE, will also have Place here.

4404.

4405.

If we compare such a Planet, with an homogenous one of the same Bigness, and which contains an equal Quantity with the heterogeneous one proposed, all the single Columns which tend from the Surface to the Center, will have less Gravity in the heterogeneous than in the homogenous Planet.

4406.

For if, *the homogeneous Planet being given, the Matter be every where removed towards the Surface, and so the Density be increased in receding from the Center*, and the Point H be taken at Pleasure, which we suppose to be transferred to b , then the Matter, which was contained in the Globe whose Semi-diameter was CH , will now fill a greater Globe, whose Semi-diameter is Ch , and in that last Case the Quantity of Matter is the same, which draws that Particle towards the Center^{*}; wherefore the Gravities of this Particle in these different Circumstances, are in a duplicate inverse Ratio of the Distances CH , Ch ^{*}, and the Gravity is less in the heterogeneous Globe.

* 4117.

4118.

* 4117.

4049.

But this Demonstration may be referred to every one of the Parts of the whole Globe, according to whatever Law the Density increases receding from the Center, because all the Particles are removed from the Center, when *none but the Particles in the Surface remain, and keep their Gravity*; and therefore every one of the Columns extended from the Surface to the Center, whose Gravity is made up of the joint Gravities of the Particles, become lighter.

4407.

* 607.

In such a changed Planet also, the centrifugal Force of every one of the Particles, except those that are in the Surface, is increased^{*}; for each of them describe bigger Circles than in the homogeneous Planet.

4408.

† 4404.

* 4402.4403.

Therefore heterogeneous Planets, such as we have above described[†], while they revolve about their Axis, do, upon a double Account, change their Figure more than homogeneous ones^{*}.

4409.

We prove by a like Demonstration, that Planets do less change their Figure, that is, are less depressed at the Poles, if the Density be increased in going towards the Center.

4410.

Hitherto we have considered a spherical Planet when it is at rest; it may also have another Figure, if we suppose a Kernel or Nucleus of solid Matter in the Middle: for if in such a Case it has the Figure of a Spheroid, and be encompassed round with fluid Matter, the Figure of the Planet will be different, according to the different Figure of the Nucleus, and it's Density.

4411.

4412.

But whatever Figure a Planet has, it is depressed towards the Pole by it's Motion about it's Axis, and the æquatorial Diameter is increased; but it does not necessarily follow from thence that that Diameter, however increased, exceeds the diminished Axis; so that *nothing, except from immediate Observations, can be determined concerning the Figure of a Planet*; which Method we shall follow in the next Scholium for determining the Figure of the Earth.

SCHOLIUM III.

How to determine the Figure of the Earth.

WE have said that the Earth was not spherical, but that the æqua- 4413.
torial Diameter was longer than the Axis*, and therefore that it * 4311.
had such a Figure as it might have acquired by a Motion about it's Axis,
if it had been spherical†; and as this Figure differs but very little from a † 4008.
Circle, we suppose the Section through the Axis, that is the Plane of a
Meridian to make an Ellipse, one of whose Axes is the Diameter of the
Æquator*. * 4385.

We also suppose that the Decrements of Gravity, receding from the 4414.
Pole, follow the duplicate Ratio of the Co-sines of the Latitudes of
Places*; that is that the Increases of Gravity, receding from the Æqua- * 4395.
tor, follow the duplicate Ratio of the Sines of the same Latitudes of
Places†. † 4397.

We have shewn that the Figure must be determined from Observati- 4115.
ons*; for that Reason therefore we have chosen two Measures taken in * 4412.
different Places, that is in *Lapland* and in *France*, and described in two
small Treatises by the famous *Monf. de Maupertuis*, to whom they are
principally owing. We prefer these to others taken in various other
Countries; because it is plain from the Description of the Instruments,
and the Cautions which the Observers affirm that they took, they could
fall into but very small, and scarce sensible, Errors.

What relates to Gravity, we deduce from the Length of a Pendulum 4416.
vibrating Seconds, measured in *France* with the utmost Care by that fa-
mous Philosopher *Monf. de Mairan*, and from the Observations made by
the same *French* Mathematicians who took Pains about measuring the Fi-
gure of the Earth in *Lapland*, with the same Pendulum in both Coun-
tries, viz. *France* and *Lapland*.

Now let CP be the Semi-axis of the Earth; Ee the Diameter of the 4417.
Æquator; and PIE an Arc of the Meridian. A small Part of that Me-
ridian iI is measured by surveying on the Surface of the Earth itself.
Now if we conceive the Lines bi, BB, which we suppose vertical, and
therefore perpendicular to the Surface of the Earth, to be continued to
the fixed Stars, an Arc in the Heavens intercepted between those Lines
is measured by Astronomical Observations; that is, an Arc which mea-
sures the Angle IAI, and determines the Arc Ii, in the Meridian.

By such Operations it has been discovered, that the Arc Ii, where the 4418.
Angle IAI is of 0. Deg. 57'.28",67, contains 55023,47 *French Toises* (or
Fathom) when the Latitude of the middle Point of the measured Arc
was of 66 Deg. 20'. From which it follows that a Degree of the Meri-
dian between the Points of Latitude of 65 Deg. 50'. and 66 Deg. 50' con-
tain 57437,9 *French Toises*; that is 29752 *Rhyndland Perches*.

It

4419. It has also appeared from such kind of Observations, that a Degree of the Meridian between the Latitudes of 48 Deg. 52', and 49 Deg. 52' contains 57183 *French Toises*, or 29620 *Rhyndland Perches*.

4420. The Bigness of one Degree being given, one may easily find the Radius of the Circle; for the Radius is to one Degree, as 180×113 to 355, that is as 4068 to 71; therefore we easily determine the Radii of the Convexity in the middle Points of the mentioned Degrees, that is, we have r for two Places; in which the Angles as IBE , which the Perpendiculars to the Surface make with the Plane of the $\text{\AA}equator$, are of 66 Deg. 20', and 49 Deg. 22'.

4421. Let us therefore suppose r , s and t to stand for those Things, which above were expressed by the same Letters, but that they belong to the first Angle; that is, r is the Radius of Convexity, supposing the Latitude of 66 Deg. 20'*; t is the Tangent, and s the Secant of the same Angle†; in the same manner we suppose r , t , s , to express the same Quantities for the Latitude of 49 Deg. 22'; in all which we suppose the Radius of the Circle, when t , s , t , s , express the said Quantities, to be equal to Unity, as above*.

* 4345. 4346.
† 4348.

* 4348.

4422. All that we have explained concerning the Computation of the Lines in an Ellipse in the 1st Scholium, may be referred to the Earth, whose Section through the Meridian, we suppose to be represented by the ninth Figure itself.

* 4344.

But before all things we must determine the Proportion between the Axes of the Ellipse, that is, between CP and CE , or u and z *.

4423.

† 4374.

* 4350.

We therefore seek a †; because $1, a :: zz, uu$ *. The Computation is easy by Logarithms; and we find $r^{\frac{2}{3}} ss = 136900,7$; $r^{\frac{2}{3}} ss = 52171,2$; $r^{\frac{2}{3}} tt ss = 271604$; $r^{\frac{2}{3}} tt ss = 185916,9$; whence we deduce $a = \frac{84720,5}{85688,1}$ *.

* 4374.

4424.

4425.

† 4344.

* 4370.

* 4424.

4426.

That is, $z, u, :: 178,3. 177,3.$ nearly.

We have now two Ways to discover z (CE)† whether we make use of r, s, t , or r, s, t , *; and Ee the Diameter of the $\text{\AA}equator$ is of 3399474 *Rhyndland Perches*; whence we deduce, that the Axis contains 3380406 *Perches*†. And the mean Diameter is of 3389940 *Perches*.

* 4369.

We find the Radius of Convexity in any Point, when it's Latitude is

given by this $\text{\AA}equation$, $r = \frac{as^3z}{1 + at\sqrt{\frac{3}{2}}}$ *.

4427.

Under the Pole the Angle IBE is a right one; therefore s and t are equal and infinite; therefore $r = \frac{z}{\sqrt{a}}$. Then the Radius of Convexity is the greatest of all.

4428.

But the Convexity is the greatest, and the Radius of Convexity the least, under the $\text{\AA}equator$. Then $s = 1$, and $t = 0$; whence $r = az$.

We

We may discover the Magnitude of a Degree of Latitude from the Radius of Convexity ; for 4068,71 : : r , to the required Degree * : and * 4429.
thus we have determined the greatest and the least Degree †. If the Mag- † 4420.
nitude of any Degree of Latitude whatever be given, the Radius of Convexity † 4330.
is determined * ; and the Latitude to which this answers, may be dif- * 4430.
* 4420.

covered by the following Æquation, $tt = \frac{r^{\frac{2}{3}} - a^{\frac{2}{3}} z^{\frac{2}{3}}}{a^{\frac{2}{3}} z^{\frac{2}{3}} - a r^{\frac{2}{3}}} \dagger$; for the † 4371.4331.

Tangent being given, the Angle is given. What has been said of the 4431.
Place of the mean Degree is built upon this Computation.

We also now easily find the Radius of any Circle of Latitude, namely

HI = CD = x ; for $x = \frac{z}{1 + att^2}^{\frac{1}{2}}$ *; and 4068,71 : : x , to the * 4362.

Degree of Longitude in that Latitude †. † 4420.

SCHOLIUM IV.

The Determination of Gravity in different Places.

WE have seen before from Observations made with a Pendulum 4432.
carried from one Place to another, that it is evident, that Gravity
at the Altitude of the Pole of 48 Deg. 50'. is to the Gravity under the
Altitude of the Pole of 66 Deg. 48', as 728,6 to 729,6 *; which being * 4335.
given, the Gravities in all Places of the Earth are compared together, by
calling to our Assistance, what we have demonstrated above †, and this † 4414.4397.
is the Rule.

*As the Difference of the Squares of the Sines of the said Angles of 66°. 48'; 4433.
and 48°. to the Difference of the Square of the Sines of one of these Angles,
and of any Angle given; so is the Difference of the Gravities in the first of
these Places, to the Difference of the Gravities in the last.*

But all the Computations become more simple if first we discover the 4434.
Gravity under the Æquator, because the Sine of Latitude and therefore
it's Square = 0.

The Lengths of Pendulums which perform their Vibrations in equal 4435.
Times, are to one another as the Gravities *, and are compared together * 431.
in the same manner as them.

We have seen that the Length of a Pendulum, which vibrates Seconds 4436.
at *Paris*, is 440,57 Lines of the *Paris* Foot, and therefore 456,42 Lines
of the *Rbynland* Foot, whence we reason thus;

728,6; 729,6 : : 456,42; 457,08 *. * 4335.431.

And we have the Length of a Pendulum for an Height of the Pole
of 66°. 48'.

As the Difference of the Squares of the Sines of the Latitudes 66°. 4437.
48'. and 48°. 50'. to the last Square, so the Difference of the Lengths

VOL. II. Ccc found,

found, 0,66 to the Difference of the *Paris* Pendulum from the Pendulum under the *Æquator* *, which is discovered to be 1,28; and the Length of that Pendulum is 455,14.

4438. As the Square of the Sine $48^{\circ}. 50'$. to the Square of the Radius, so is 1,28 to 2,26 the Difference of the Length under the *Æquator* and the Pole, in which Place therefore the Length of a Pendulum is 557,40.

4439. For any other Latitude whatever we work thus: As the Square of the Radius, namely of the Sine of the Latitude of the Pole itself, is to the Square of the Sine of the given Latitude, so is 2,26, the Length to be added to a Pendulum under the *Æquator* to have the Pendulum under the Pole, to the Length to be added to that same Pendulum under the *Æquator*, to have a Pendulum that will vibrate Seconds in a Place pro-

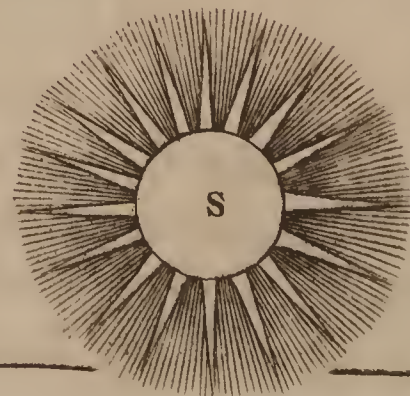
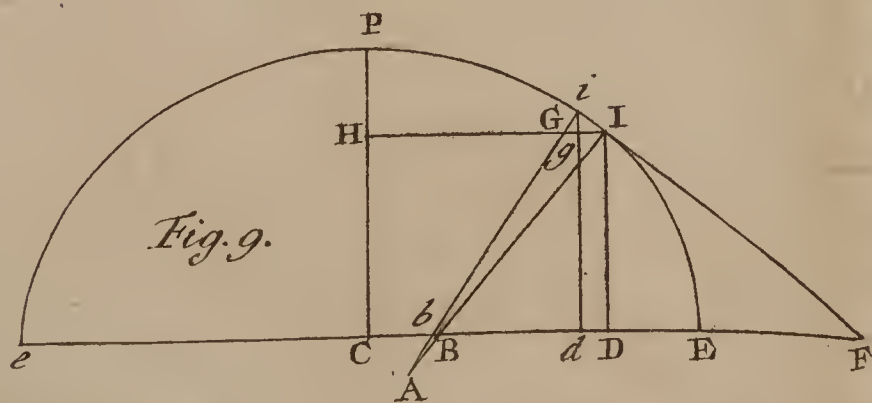
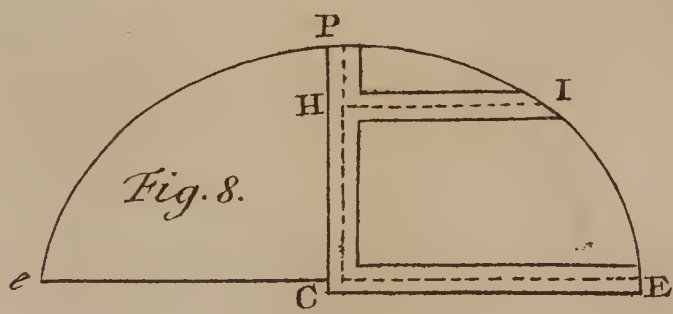
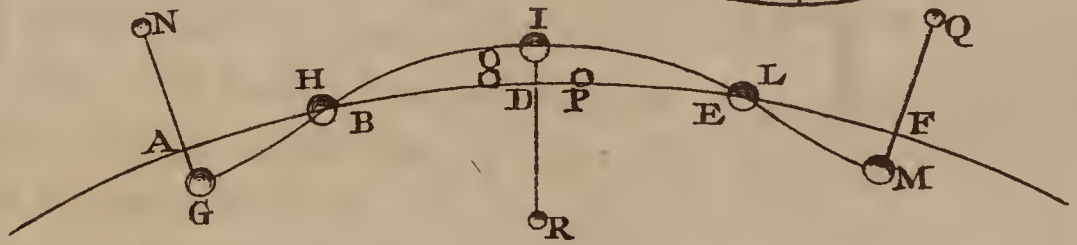
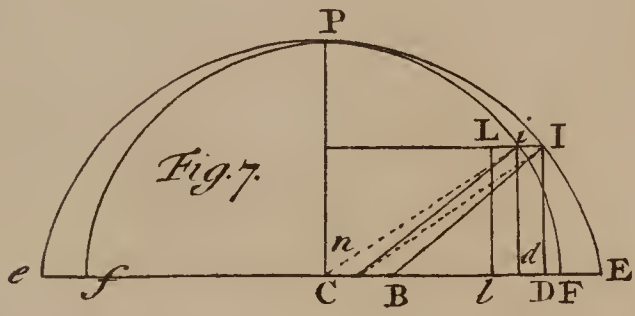
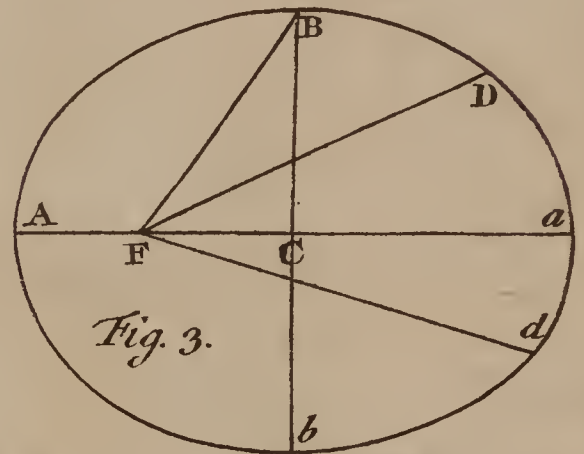
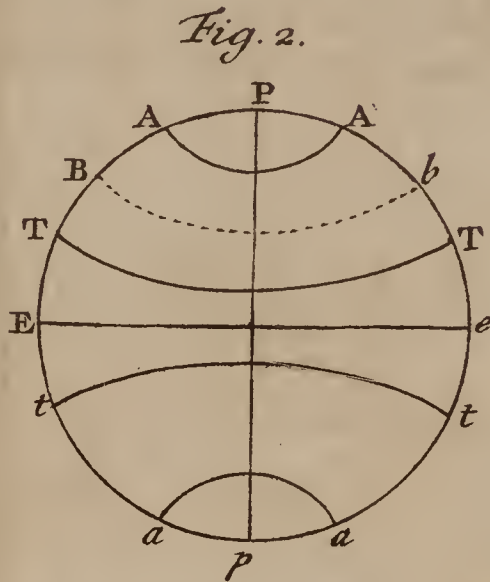
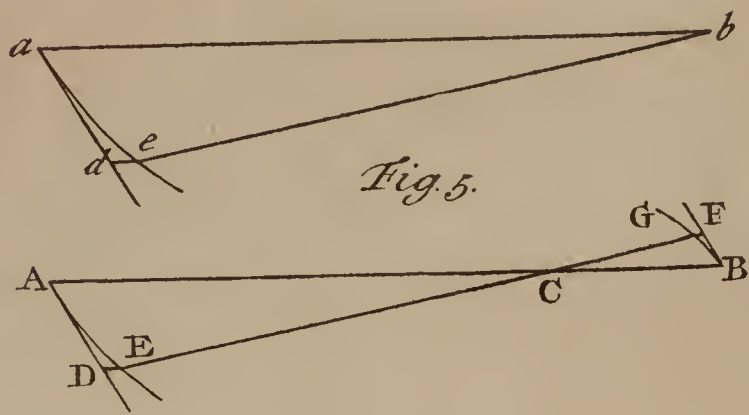
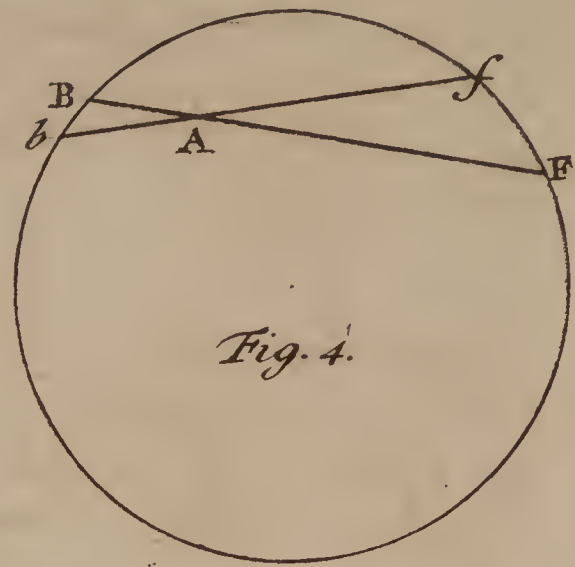
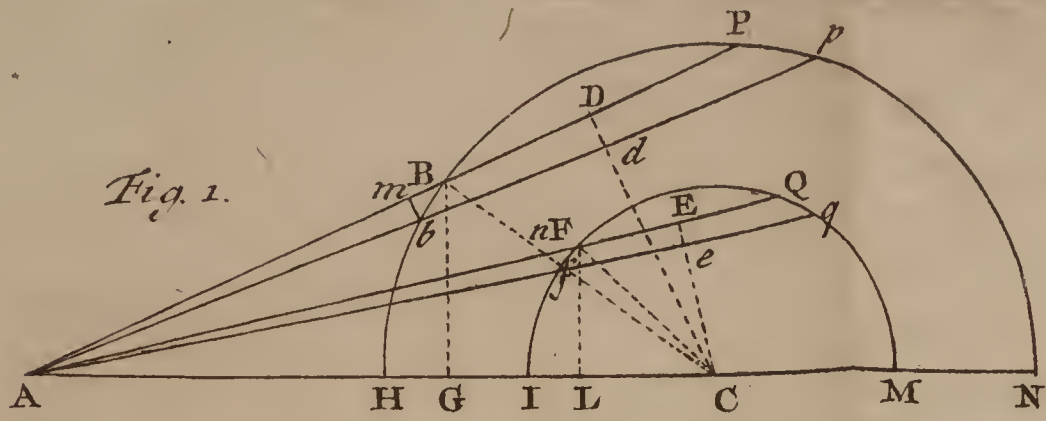
* 4433. posed *.

C H A P. XVIII.

The physical Explanation of the Motion of the Earth's Axis.

4440. **T**HAT the Nodes of the Moon go back, that is, are moved
 * 4289. in *Antecedentia* *, and that the Inclination of it's Orbit is
 † 4295. liable to Change †, we have already demonstrated; let us conceive
 several Moons to be at the same Distance, revolving in equal
 Times about the Earth, in a Plane inclined to the Plane of the
 Ecliptic; it is evident they will all be agitated by the same Mo-
 tions: Let us conceive the Number of the Moons to be increased,
 so as to touch one another, and form a Ring, whose Parts cohere;
 whilst one Part of the Ring is attracted, to increase the Inclination,
 the other Part is agitated by a contrary Motion, to diminish it's In-
 clination *; the greater Force in this Case prevails, that is, in the
 * 4293. Motion of the Line of the Nodes, from the Quadratures towards the
 4441. Syzygies, the Inclination of the Ring is diminished in each of it's Re-
 * 4297. volutions *; and it is the least of all when the Line of Nodes is in the
 † 4298. Syzygies †. On the contrary it's Inclination is increased, when the
 4442. Line of Nodes is carried from the Syzygies towards the Quadratures *;
 * 4299. and it is the greatest of all, when the Line of the Nodes is in these
 † 4300. last †. The Line of the Nodes is continually carried in Antecedentia,
 4443. unless when it is at rest in the Syzygies *.
 * 4289. 4292. If the Quantity of Matter in the Ring be diminished it's Motions
 4444. will not be changed; because they depend upon Gravity, which acts
 * 4048. equally upon every Particle of Matter *.

If



Chap. 18. of Natural Philosophy.

379

*If the Diameter of the Ring be diminished, these Motions are diminished in a Ratio of this Diminution *, but none of them wholly * vanish; and it is agitated by the same Motions though less.*

4445.

4302.

Let us conceive the Earth to be spherical; and in the Plane of the $\mathcal{A}$ equator, which makes an Angle of 23 Deg. 29 Min. with the Plane of the Ecliptic, let there be a Ring, revolving in the same Time as the Earth; let it be diminished so as to touch the Earth and cohere with it; by this the aforesaid Motion of the Ring will not be destroyed; for since the Earth is kept in a determinate Situation by no Force, it yields to the Impressions of the Ring, whose Agitations are yet diminished, the Matter to be moved being increased, and the moving Force remaining the same.

4446.

And this is truly the Case; for the Figure of the Earth is spherical, encompassed with the Ring at the $\mathcal{A}$ equator, whereby the Earth is more elevated towards the $\mathcal{A}$ equator *, the Line of Nodes * of which Ring is the Section of the Planes of the $\mathcal{A}$ equator and Ecliptic. Whence we deduce the following Conclusions.

4447.

4311.

*In the $\mathcal{A}$ equinoxes, the Inclination of the $\mathcal{A}$ equator is least of all *; and therefore the Inclination of the Axis is the greatest; for it makes a right Angle with the Plane of the $\mathcal{A}$ equator †. Afterwards, the Inclination of the $\mathcal{A}$ equator is increased, that is, the Inclination of the Axis is diminished, till the Sun comes to the Solstices, where this Inclination of the Axis is the least of all, and that of the $\mathcal{A}$ equator is the greatest *.*

4448.

4441.

3879.

4449.

* 4442.

Therefore twice in a Year the Inclination of the Axis of the Earth is diminished and twice increased. And the Section of the Plane of the $\mathcal{A}$ equator with the Plane of the Ecliptic, which is at rest in the $\mathcal{A}$ equinoxes, the rest of the Time is moved in Antecedentia *.

4450.

4451.

* 4443.

4452.

The Plane of the $\mathcal{A}$ equator is also inclined to the Plane of the Moon's Orbit; for it makes a small Angle with the Plane of the Ecliptic †; and therefore the Moon acts in the same manner upon the Ring as the Sun; and although the Moon be less, yet, because it is much less distant than the Sun, it exerts a greater Action upon the Ring. Wherefore also the Inclination of the Axis of the Earth to the Plane of the Moon's Orbit * (and consequently to the Plane of the Ecliptic) is twice changed in every Revolution, and twice restored by the Action of the Moon: and the Section of the Plane of the $\mathcal{A}$ equator, with the Plane of the Moon's Orbit *, is carried in Antecedentia: From which Motion it necessarily follows, that the Section of the Plane of the $\mathcal{A}$ equator, with the Plane of the Ecliptic, changes it's Place.

† 3742.

4453.

4450.

* 4451.

4454. *The Changes of the Inclination of the Axis are too small to be observed; but the Change of Place of the Line of the Æquinoxes, and the*
 4455. *Motion of the Axis which follows from it, being always carried the same Way, at last becomes sensible; and from these follow the Phæ-*
 * 4017. 4018. *nomena before explained *.*

C H A P. XIX.

Concerning the Tides.

4456. **S**INCE the Tides depend upon the abovementioned Actions of the Sun and Moon, they must not be neglected here.
 That we may explain them from the Principles already laid down, we must consider that the Earth, as also all Bodies near it,
 * 4047. gravitate towards the Moon *; therefore the Particles of Water in the Earth's Surface, which tend towards the Earth's Surface, which
 † 4325. tend towards the Center of the Earth, or near it, are carried with it towards the Moon †. Since also the solid Mass of the Earth is
 * 4082. carried towards the Moon, according to the Laws which would obtain, if all the Matter of which it consists was collected in it's Center *; *what has been demonstrated in Chap. xvi. of the Action of the*
 4457. *Sun upon the Moon, falling towards the Earth, whilst with the Earth it goes towards the Sun, may be applied to the Action of the Moon upon the Particles of Water in the Earth's Surface, which don't cohere with the Mass of the Earth, but tend towards it's Center, and continually with it's Mass fall towards the Moon; by which*
 * 4210. *Force, as we have shewn *, the Earth is kept in it's Orbit, about the common Center of Gravity of the Earth and Moon.*
 4458. Let S be the Moon; ALB/ the Surface of the Earth, whose
 Plate 127. Mass tends towards the Moon, as if it was all collected at T; by
 Fig. 1. the Action of the Moon, the Particles of Water, A and B, acquire
 * 4219. a greater Gravity towards T *; on the contrary, the Particles at L/,
 † 4225. 4228. lose of their Gravity †; whence we deduce, that if the whole Earth was covered with Water, there would not be an Æquilibrium unless this Water was more elevated in the Points L and /, than in a whole Circle 90 Deg. distant from these Points; and therefore passing through the Points A and B; and therefore *by the Action of the Moon the Water acquires a spheroidical Figure, formed by the Revolution of an Oval about it's greater Axis, which, being continued, goes through the Moon.*

Let

Chap. 19. of Natural Philosophy.

381

Let us suppose the Moon in the *Æquator*; all the Sections of the Earth which are parallel to the *Æquator*, as they are also parallel to the Axis of the Spheroid*, are oval, whose greater Axes pass* through the Meridian of the Moon; whence it follows, that *the Earth being at rest, in any Circle of Latitude, the Water is more elevated in the Meridian in which the Moon is, and in the opposite Meridian, than in the intermediate Places.*

4460.

4459.

4461.

DEFINITION.

The lunar Day is the Time spent between the Moon's going from the Meridian and coming to it again. This Day is divided into 24 lunar Hours: It is 50 Minutes longer than the natural Day.

4462.

From the Motion of the Earth round it's Axis, every lunar Day, every Place passes through the Meridian of the Moon; and the opposite Meridian, that is, twice passes through that Place, where the Water is raised by the Action of the Moon, and twice through that Place, where the Water is depressed by the same Action*; and so* in a lunar Day the Sea is twice elevated, and twice depressed, in any assigned Place.

4463.

4464.

4461.

By the Motion of the Earth round it's Axis, the elevated Water continually recedes from the Meridian of the Moon; yet by the Action of the Moon*, the Axis of the Spheroid passes through the Moon; therefore the Water is continually agitated, that the Elevation, which on account of the Motion of the Earth is removed, may be brought under the Moon. Therefore the Water continually flows from A and B towards L and l, whilst by the Motion of the Earth, the Elevation is carried from L towards B, and from l towards A; that is between L and B, as also between l and A, there are two contrary Motions, by which the Water is accumulated more; so that the greatest Elevations are between these Points (viz.) not directly under the Moon, but on one Side of that Point, and likewise aside of the opposite Point, that is in any Place, the Water is most elevated, two or three Hours after the Moon has passed the Meridian of the Place, or the opposite Meridian.

4465.

4459.

4466.

The Elevation of the Waters towards the Moon a little exceeds the opposite one*, the Ascent of the Water is diminished as you go towards the Poles, because there is no Agitation of Water there.

4467.

4468.

* 4457. 4229.

What has been demonstrated, in relation to the Moon, may be applied to the Sun; therefore from the Action of the Sun, every natural Day the Sea is twice elevated, and twice depressed*. This* Agitation.

4469.

4464.

4470. *Agitation is much less, on account of the immense Distance of the*
 4471. *Sun than that which depends upon the Moon; yet it is subject to the*
same Laws.

4472. The Motions, which depend upon the Actions of the Moon and
 4473. Sun, are not distinguished but confounded, and *from the Actions of*
the Sun, the lunar Tide is only changed, which Change varies every
Day, by reason of the Inequality between the natural and lunar

* 4462. *Day*.*

4474. *In the Syzygies, the Elevation, from the Actions of both Lumi-*
naries, concur, and the Water is more elevated.

The Sea ascends less in the Quadratures; for where the Water is
elevated by the Action of the Moon, it is depressed by the Action
 4475. *of the Sun, and so on the contrary. Therefore, whilst the Moon*
passes from the Syzygy to the Quadrature, the daily Elevations are
continually diminished: On the contrary, they are increased, when
the Moon moves from the Quadratures to the Syzygy.

4476. *At a new Moon also, cæteris paribus, the Agitations are greater, and*
those, that follow one another the same Day, are more different than at
 * 4467. 4471. *a full Moon*.*

4477. *The greatest and least Elevations are not observed, till the second*
or third Day after the new or full Moon; because the Motion ac-
quired is not presently destroyed from the Attrition, and other
Causes, by which acquired Motion the Ascent of the Water is in-
creased. Although the Action by which the Sea is raised be di-
 * 4006. *minished; somewhat like to what we have demonstrated elsewhere*
concerning Heat.*

4478. If now we consider the Luminaries receding from the Plane of
 the Æquator, we shall perceive that *the Agitation* is diminished,
 and becomes *less, according as the Declination of the Luminaries be-*
comes greater. Which plainly appears, if we conceive them to be
 in the Poles; for then the Axis of the spheroidical Figure coincides
 with the Axis of the Earth; and all the Sections, that are parallel
 to the Æquator, are perpendicular to the Axis of the Spheroid, and
 therefore circular. So that the Water, in every Circle of Latitude,
 will have every where the same Elevation; and so in the Motion of
 the Earth, the Height of the Sea is not changed in particular Places.
 If the Luminaries recede from the Poles, it is easy to find, that the
 Agitation will be more and more increased till it be the greatest of
 all, the Spheroid revolving about a Line perpendicular to the Axis,
 the Axis of the Spheroid being supposed in the Plane of the
 Æquator.

Hence

Hence it is plain, why *in the Syzygies, near the Æquinoxes, the Tides are observed to be the greatest*, both Luminaries being in or near the Æquator.

4479.

The Actions of the Moon and Sun are greater, the less those Bodies are distant from the Earth *; but when the Distance of the Sun is less, and it is in the South Signs, often both the greatest æquinoc-tial Tides are observed in the Situation of the Sun; that is, before the vernal, and after the autumnal Æquinox, which yet does not happen every Year; because some Variation may arise from the Situation of the Moon's Orbit, and the Distance of Syzygy from the Æquinox.

4480.

4302.

In Places distant from the Æquator, as the Luminaries recede from the Æquator, the Elevations that happen the same Day are unequal. Plate 127. Let P P be the Axis of the Earth, E E the Æquator, L l a Circle

4481.

Fig. 8.

of Latitude; A B the Axis of the spheroidical Figure which the Water forms: When a Place in the Circle L l is given at L or l, it is given in the same Meridian with the Axis of the Spheroid, and the Water is most elevated, in both Cases; yet at L it is more elevated than at l; for C L exceeds C l, which Lines measure the Heights of the Waters, that is the Distances from the Center: These Lines would be equal if A L and B l, (which are the Distances from the Axis of the Spheroid) were equal. But C l is less, because B l exceeds A L, which arises from the Inclination of the Axis of the Spheroid to the Æquator.

As long as the Moon is on the same Side of the Æquator with any Place, that is, towards the Line C A continued, the Elevation of the Water is observed to be greatest every Day, after the Moon has passed the Meridian of the Place, for there is the greatest Elevation when the Place is come to L; but the Æquator separates, or is between the Moon and the Place, of which we speak, that is, if the Moon be towards the Line C B continued, the Water again at L will come to the greatest Height, and, every Day, the greatest Elevation of the Sea will be, after the Moon has passed through the opposite Meridian.

4482.

4483.

All Things, which have been hitherto explained, would exactly obtain, if the whole Surface of the Earth was covered with Sea; but since the Sea is not every where, some Changes arise from thence not indeed in the open Sea; because the Ocean is extended enough to be subject to the Motions we have spoken of. But the Situation of the Shores, the Streights, and many other Things depending upon the particular Situation of the Places, disturb these general Rules.

4484.

4485.

Rules. Yet it is plain from the most general Observations, that the Tide follows the Laws which we have explained.

4486. What remains is, to determine the Forces with which the Sun and Moon act upon the Sea, that it may appear, that they are able to produce the Effects which we have mentioned; and that the Actions of those Bodies, upon Pendulums and other Bodies, are insensible.

4487. The Increase or Addition to the Gravity of the Moon in the Quadratures, from the Action of the Sun, is to the Gravity of the

* 4229. Moon towards the Earth, as 1 to 178, 73 *. In which Computation we have supposed the mean Distance of the Moon, from the

‡ 4217. Center of the Earth, to be 60 Semidiameters of the Earth ‡; therefore the Gravity of the Moon is to the Gravity on the Earth's Sur-

* 4049. face, as 1 to $60 \times 60 = 3600$ *. Therefore the abovementioned Increase is to the Gravity on the Earth's Surface, as 1 to 643428, in which Computation there is an Error to be corrected.

4488. This Computation would be exact, if the Increase, of which we speak, was to the Force, with which the Earth descends towards the

* 4219. Sun, as the Distance of the Moon (which is 60 Semidiameters of the Earth) to the Distance of the Earth from the Sun *; but it is as the true mean Distance of the Moon, which is $60\frac{1}{2}$ Semidiameters of the Earth, to the Distance of the Earth from the Sun. Wherefore the Increase, that we have just determined, ought to be $\frac{1}{120}$ Part increased, and will be to the Force of Gravity on the Earth's Surface, as $\frac{1}{120}$ to 643428, or as 1 to 638110.

4489. This Increase of the Gravity of the Moon, in the Quadratures from the Action of the Sun, is to the Increase of the Gravity of the Water on the Earth's Surface, in Places which are 90 Deg. distant

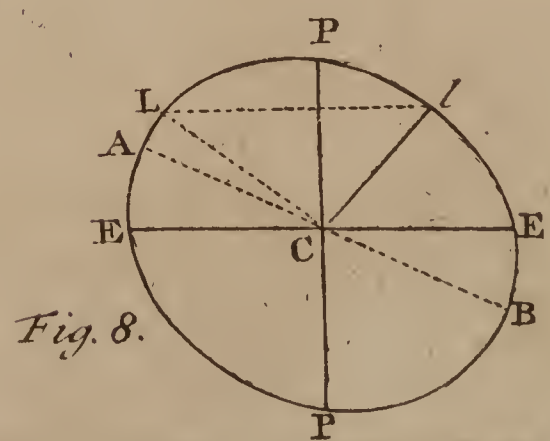
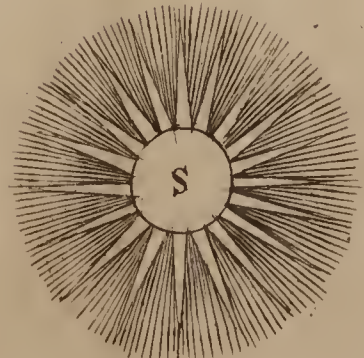
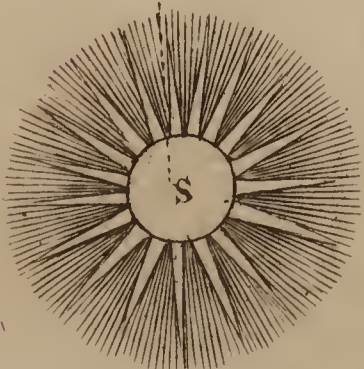
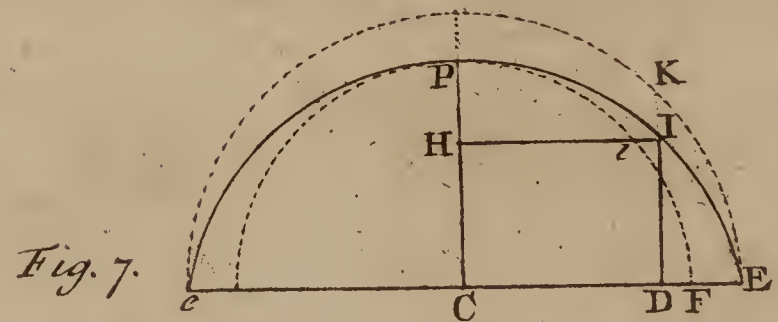
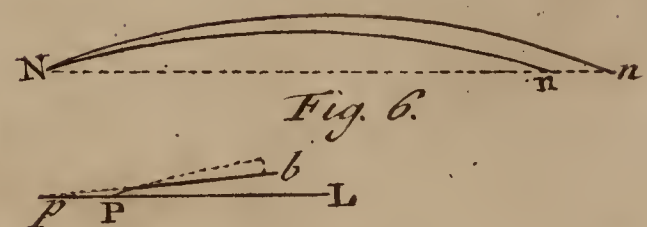
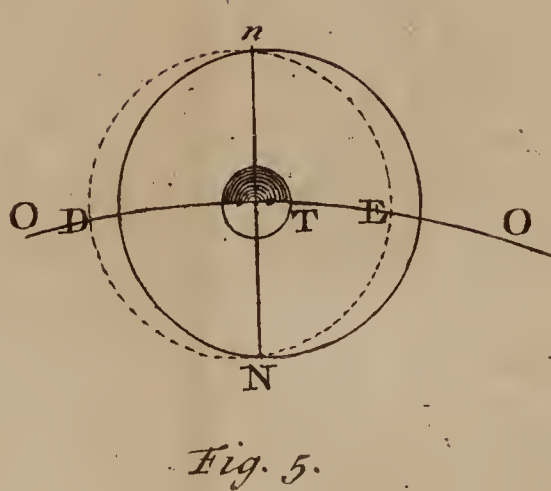
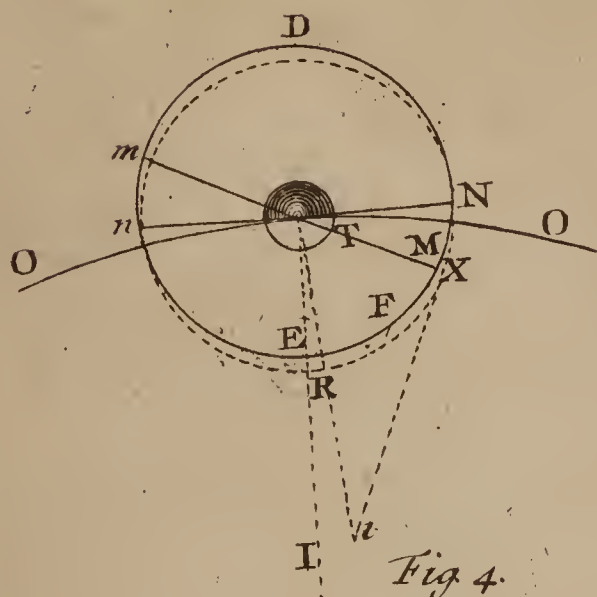
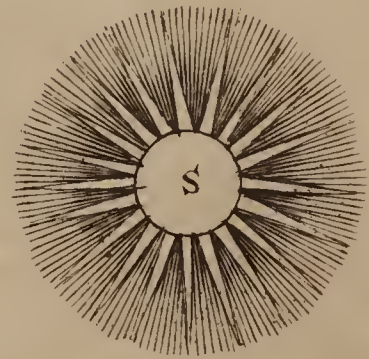
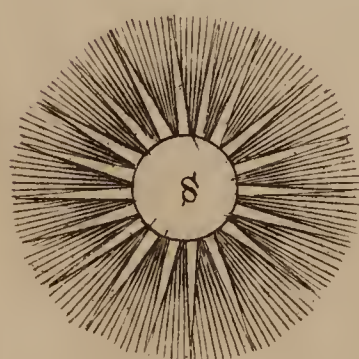
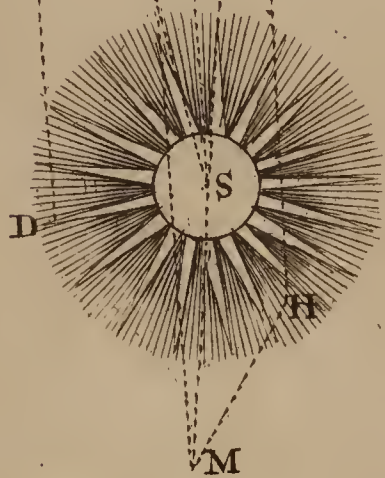
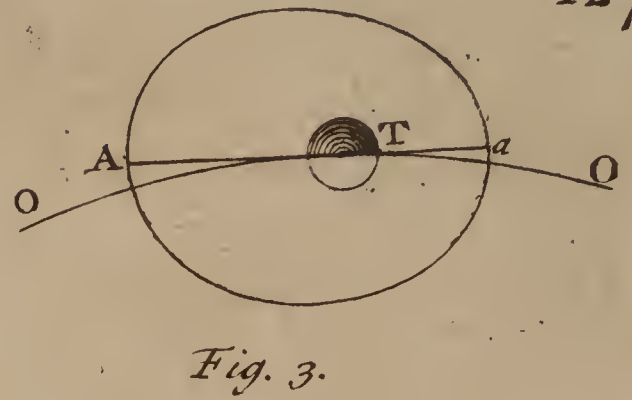
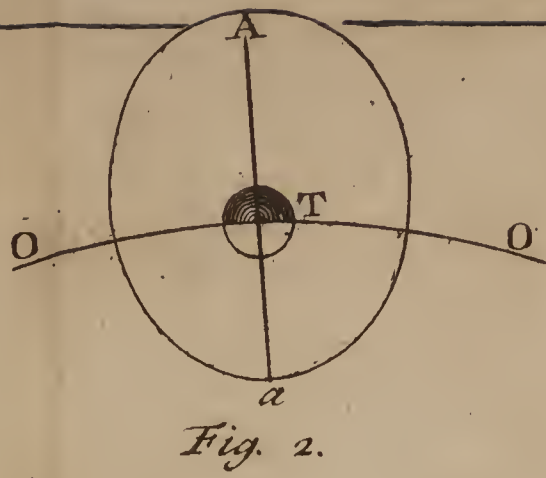
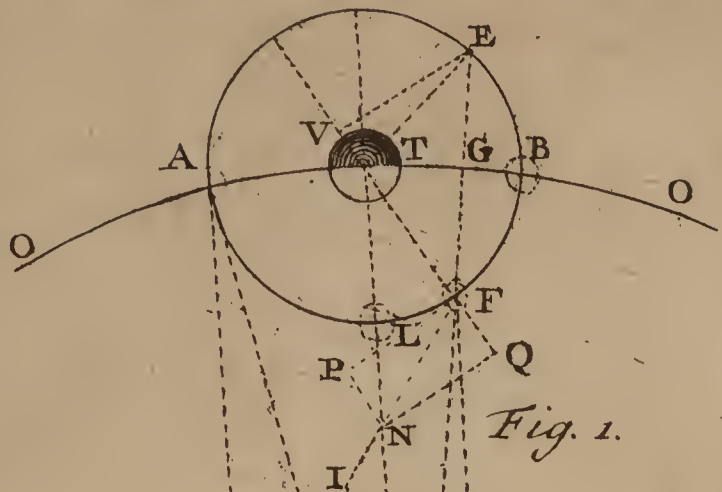
* 4220. from the Sun, (from the same Action of the Sun) as $60\frac{1}{2}$ to 1 *. Therefore this Increase of the Gravity is to the Gravity of the Water itself as 1 to 38605679. The Diminution of the Gravity,

* 4230. under the Sun, and in the opposite Place, is double this Increase *;

4490. therefore it is to the Gravity as 1 to 19302839, and *the whole Change in the Gravity, arising from the Action of the Sun, is to the Gravity itself, as 1 to 12868560.*

4491. In order to compare the Action of the Moon with the Action of the Sun, we must make Experiments in Places, in which, by reason of the Narrowness, the Sea is sensibly raised. Near *Bristol*

* 4479. at the Autumn and Spring, at which Times the Agitation of the Sea is greatest *, the Water ascends in the Syzygies about 45 Feet, more or less, in the Quadratures about 25 Feet, more or less. Which Numbers are to one another, as 9 to 4. The



The Determination of the Forces, which we would find, if the greatest and least Elevations were exactly at the Time of the Syzygies, would be very easy, which we have shewn before not to happen so *.

4492.

The Distance of the Moon from the Syzygy, or the Quadrature, is not always the same in the greatest or least Elevation; for this Distance varies, because the Moon is sometimes more and sometimes less, distant from the Meridian, when it goes through the Syzygy or Quadrature. The mean Distance of the Moon from the Syzygy, or Quadrature, to which the aforesaid Observations ought to be referred, is about 18 Deg. 30 Min. so that the whole Action of the Sun neither conspires with the Action of the Moon in the Syzygies, nor acts contrary to it in the Quadratures. Also in such a Case, if at the Syzygy, both the Luminaries be in the Æquator, in the said Distance from the Quadrature, the Declination of the Moon is 22 Deg. 13 Min. more or less; whereby the Force of the Moon to move the Sea is diminished *. Besides, *cæteris paribus*, * the Distance of the Moon from the Earth at the Syzygies is less, than at the Quadratures †; whence also the Action of the Moon is diminished at the Quadratures *: By attending to all which Things * we may discover, that *the mean Force of the Sun, to move the Sea, is to the mean Force of the Moon to move the same as 1 to 4*, But the Force of the Sun is to the Force of Gravity as 1 to 12868560*; wherefore *the Force of the Moon is to the same Force of Gravity, as 1 to 2871485*. From whence it follows, that these Forces of the Moon and Sun are too small, to be sensible in Pendulums and other Experiments; but it is easily proved, that they are capable of agitating the Sea.

* 4477.

4493.

* 4478.

† 4254.4256.

* 4480.

4494.

* 4490.

4495.

By diminishing the Gravity on the Earth's Surface $\frac{1}{202}$, Part, the Sea is raised to the Height of 9534 Perches, that is 114408 Rbynland Feet *. For each Perch contains 12 Feet; whence by the Rule of Proportion †, we find that *the Action of the Sun changes the Height of the Sea near two Feet, and that the Action of the Moon changes it 7,83; and that from the joined Action of both, the mean Agitation is about 10 Feet*, which agrees pretty well with Observations, for in the open Ocean, as the Sea is more or less open, the Water is raised to the Height of six, nine, twelve, or fifteen Feet; in which Elevations also there is a Difference arising from the Depth of the Waters, where the Sea violently enters into Streights or Gulphs; the Force is not broken, till the Water rises higher.

4496.

* 4333.4322.

† 4490.

4497.

4498.

4499.

4500.

C H A P. XX.

Of the Moon's Density and Figure.

4501. **T**HE Forces of the Sun and Moon, for giving Motion to the Sea, are to one another, in a Ratio compounded of the Ratio of the Quantities of Matter in these Bodies * (for all the Particles of Matter act) and the inverse Ratio of the Cubes of the Distances of the Sun and Moon from the Earth †.

* 4048. The Quantities of Matter are in a Ratio compounded of the Ratio of the Bulks, that is, of the Cubes of the Diameters *, and the Ratio of the Densities †; wherefore the Forces abovementioned are directly as the Densities, and the Cubes of the Diameters, and inversely as the Cubes of the Distances. Here we speak of the mean Densities, as we have determined them above for different Planets *.

† 4457. 4471. 4302. The apparent Diameters of Bodies, that is, the Angles under which they are seen, increase as the Diameters themselves, and diminish as the Distances; that is they are directly as the Diameters, and inversely as the Distances; therefore the Ratio compounded of the Ratios of the Cubes of the apparent Diameters of the Sun and Moon, and of the Ratio of the Densities, will be the Ratio of the Forces, whereby those Bodies act upon the Sea. Therefore the Densities of those Bodies are directly as those Forces, whereby they move the Sea, and inversely as the Cubes of their apparent Diameters; and dividing the Forces by the Cubes of those Diameters, you have the Ratio of the Densities.

4505. The Force of the Sun is to the Force of the Moon, as 1 to 4, * 4494. 4815 *; the mean apparent Diameter of the Sun is 32 Min. 12 Sec. and the mean apparent Diameter of the Moon is 31 Min. 16½ Sec. that is, they are to one another, as 3864 to 3753. Therefore the Density of the Sun is to the Moon's Density, as 10000 to 48911: which Density of the Moon may be compared with the Densities of Jupiter, Saturn, and the Earth * and the Moon is denser than the Earth.

4507. The Quantities of Matter in two Bodies are to one another, in a Ratio compounded of the Densities and Bulks *; that is, if the Bodies be Spheres, in a Ratio compounded of the Densities and the Cubes of the Diameters.

Chap. 20. of Natural Philosophy.

387

The Densities of the Moon and Earth are to one another as 48911 to 39539 *; the Diameters as 20 to 73†. Therefore Quantities of Matter, in those Bodies, are as 1 to 39, 31. or as 0, 0512 to 0, 0013. Though the Densities be discovered, if you suppose the Bodies to be homogeneous; yet the Quantities of Matter will be rightly defined, though the Bodies are not homogeneous; for we determine the Density which that Body would have, if the Matter, of which the Body really consists, was equally diffused all over it *.

* 4171.

The Gravities, on the Surfaces of the Earth and Moon, are determined, by multiplying the Densities by the Diameters *, that is, they are to one another nearly as 3 to 1, or as 431 to 146, which Number also does express the Relation of Gravity on the Surface of the Moon, with the Gravities on the Surfaces of the Sun, Jupiter and Saturn *.

4508.

* 4086.

* 4166.

4510.

The common Center of Gravity of the Moon and Earth, about which both Bodies are moved, is determined; for it's Distance, from the Center of the Earth, is to the Distance between the Centers of both Bodies, as the Quantity of Matter in the Moon to the Quantity of Matter in both Bodies *; therefore 40, 31 is to 1: as the Distance of the Moon, from the Earth, is to the required Distance of the Center of Gravity, from the Center of the Earth, which is found to be of 2543927 Perches, as is deduced from the known Diameter of the Earth *, and the Distance of the Moon.

* 611.613.

* 3750.4321.
3740.

To determine the Figure of the Moon, we must examine what Figure it would have, if it was fluid *. If we consider the Moon alone at rest, it would be spherical †: If we consider the Action of the Earth upon the Moon, the Moon would acquire the Figure of a Spheroid, whose Axis would go through the Earth *. The Force of the Earth, for changing the Figure of the Moon, is to the Force of the Moon upon the Earth, as 39, 31. to 1 †; and as the Diameter of the Moon to the Earth's Diameter †, which are to one another as 20 to 73 *, and the Ratio compounded of these is 10, 77 to 1. This Force of the Moon is to the Gravity upon the Earth's Surface, as 1 to 2871485 †; which Gravity on the Earth's Surface is to the Gravity on the Surface of the Moon, as 431 to 146 *, or as 2871485 to 973166; wherefore the Action of the Earth, for changing the Moon's Figure, is to the Gravity upon the Moon's Surface, as 10, 77 to 973166, or as 1 to 90359, the Gravity being changed on the Earth's Surface by $\frac{1}{2871485}$ Part,

4511.

* 4307.

† 4308.

* 4459.

† 4508.4048.

† 4457.4302.

* 3751.

† 4495.

* 4509.

4512.

- * 4498. the Water is raised 8 Feet *; and therefore if Gravity was to be changed $\frac{1}{90359}$ Part, the Elevation would be 254 Feet, as is found by the Rule of Three. If keeping this Diminution of Gravity, we consider a less Body, this Height must be diminished, in Proportion to the Diameters: therefore, from the Action of the
4513. Earth, this Elevation of the Moon is of 70 Feet; and *if the Moon be homogeneous, there will not be an Æquilibrium, unless the Axis of the Spheroid exceeds the Diameter, which is perpendicular to it, 140 Feet.*
4514. The Elevation of the Moon, from the Action of the Earth, may be discover'd by one single Proportion, by knowing the Elevation of the Sea from the Moon's Action; for these Elevations are in a duplicate inverse Ratio of the Gravities on the Surfaces of those Bodies; of which Rule this is the Demonstration.
4515. If equal Forces acted on those Bodies, they would acquire similar Figures; because the Forces act in the same manner upon every Part. The Rises therefore would be to one another as the Diameter.
4516. These Rises also will be as the Forces themselves, which are as the Quantities of Matter in the Bodies acting, and as the Diameter
- * 4220. of the Bodies, whose Figures were changed *. Joining all the Ratios, the Rises of Water in the Moon and Earth, are in a direct duplicate Ratio of the Diameters of those Bodies, and the inverse Ratio of the Quantities of Matter in them, that is, in the inverse Ratio of the Gravity on their Surfaces.
4517. To which Ratio, this very Ratio is to be added to make it duplicate; because the Rises are also inversely as the Gravities acting on the Particles which are raised.
4518. If, supposing the Moon to be of the Figure which we have now determined, we conceive the Parts to cohere, *the Æquilibrium between the Moon's Parts will not be given, unless the Axis of the Spheroid be directed towards the Earth; whence we see why the Moon always turns the same Face towards the Earth; for by the continual Agitation by which the Axis of the Spheroid is directed towards the Earth, the Moon at last has acquired a Motion about*
- * 3743.3899. *another Axis, of which Motion we have treated before *: which*
4519. *Motion is performed in the same Time as the Moon turns about the Earth; which follows from the before-mentioned Action; for if the Celerity was greater, it would be continually retarded by the same Force by which the Moon always turns the same Face towards the Earth; but it would be accelerated continually, if the Celerity was less.* Yet

Chap. 20. *of Natural Philosophy.*

389

Yet this Force is great enough, to disturb sensibly at each Revolution the *Æquability* of the Motion acquired about the Axis: therefore, *the Motion about the Axis is equable, though the Moon be moved in it's Orbit by an unequal Motion* *. The Situation also of * 3739.
the Axis of the Moon, cannot be so changed by the Force above-mentioned, as to be always perpendicular to the Plane of the Orbit, whilst it's Inclination is changed †, therefore the *Axis of* † 4293.
the Moon is a little inclined to the Plane of the Orbit, as we have 4522.
before shewn *. * 3904.

The End of the SIXTH BOOK.



I N D E X.

The Number I. and II. refer to the first and second Volume, *p.* stands for page, and *n.* for the number in the margin.

A.

ACCCELERATION of a Body in a Fluid, in Moments infinitely small, is equable, I. *p.* 461. *n.* 2003. *p.* 471. *n.* 2059.
— of a Body specifically heavier than a Fluid, that descends in it, or specifically lighter, that ascends in it, I. *p.* 445. *n.* 1977. and following. *p.* 469. *n.* 2051. and fol.
— of what Kind, when several Actions together move a Body, I. *p.* 271. *n.* 1148. and fol.
— of a Body moving towards a Center, I. *p.* 134. *n.* 582. and fol. *p.* 148. and fol. *Action*, I. *p.* 166. *n.* 688.
— of a Body on a Lever, in what Ratio, I. *p.* 252. *n.* 1080.
— of different Bodies upon Light, of what Kind, II. *p.* 137. *n.* 2841.
— of two Bodies carried in different Directions, that run directly against a third Body at the same Time, I. *p.* 290. *n.* 1199. and fol. *p.* 292. *n.* 1208. and fol.
— the same can take away or communicate the same degree of Velocity, I. *p.* 169. *n.* 713.
— of a Spring. See *Spring*.
— and Resistance differ only relatively, I. *p.* 167. *n.* 695.
— a small one sometimes infinitely exceeds another small one. I. *p.* 178. *n.* 752.
— in Collision is equal to the Re-action, I. *p.* 228. *n.* 984.
— whole in a Lever, in what Ratio, I. *p.* 144. *n.* 510. and fol.
— by which a Body is moved, how found, I. *p.* 168. *n.* 706.
— by which a Spring is bent, how determined, I. *p.* 327. *n.* 1340.
— in a Lever, the smallest, I. *p.* 111. *n.* 495.

Action, greatest of an Animal. See *Animal*.

— smallest in a Machine, when the weight and Power are determined, I. *p.* 115. *n.* 514.

— smallest of all in a Machine, I. *p.* 110. *n.* 493.

— mutual of a Body and Fluid is the same, whether the Body or Fluid be moved, I. *p.* 437. *n.* 1892.

— of elastic Bodies is illustrated, I. *p.* 267. *n.* 1137. and fol.

— all requires Resistance. I. *p.* 80. *n.* 362. and fol.

— of a Power may be resolved into two, I. *p.* 67. *n.* 319.

— of a Pressure, in what Ratio, I. *p.* 171. *n.* 723.

— with which a Body in Motion runs against two Planes, is determined, I. *p.* 282. *n.* 1177. and fol.

The *Action*, which drives Water upwards. See *Water*.

— respective sometimes to be distinguished from the absolute, I. *p.* 230. *n.* 995.

— whole in a Lever of the third Kind, I. *p.* 115. *n.* 515.

— smallest, how determined, I. *p.* 120. *n.* 536. and fol.

The same *Action* is produced by a Point running through a determinate Space, whether the Point be moved faster or slower, I. *p.* 171. *n.* 728. *p.* 199. *n.* 836. and fol.

The *Actions* of two Powers may be reduced to one, I. *p.* 67. *n.* 318.

— whole in different Levers, I. *p.* 114. *n.* 511. and fol.

— in the Lever, I. *p.* 45. *n.* 235. and fol.

— of Powers, I. *p.* 28. *n.* 124. and fol.

— if several act upon a Body, what Velocity they communicate to it, I. *p.* 271. *n.* 1148. and fol.

Actions,

I N D E X.

- Actions*, what are applied to Hydraulic Machines. See *Hydraulic*.
- of Forces. See *Forces*.
- Addition* mechanical, I. p. 44. n. 227.
- Adnata*, II. p. 173. n. 3063.
- Æolipile*, II. p. 69. n. 2441. and fol.
- Equation* of Jupiter's Satellite, the first, II. p. 100. n. 2626.
- the second, II. p. 100. n. 2628.
- of Time. See *Time*.
- Equator* cœlestial. II. p. 300. n. 3879.
- Equilibrium* of unequal Bodies in the Air, is destroyed in Vacuo, II. p. 19. n. 2166. and fol.
- of a Balance, I. p. 38. n. 190.
- Equinoctial* Points, II. p. 311. n. 3982.
- Equinoxes*, precession of, II. p. 315. n. 4021. and fol. p. 316. n. 4031.
- explanation of this Motion, II. p. 378. n. 4440. and fol.
- Equiponderate*, I. p. 38. n. 191.
- unequal Bodies may, *ibid.* n. 192. p. 39. n. 196.
- many Bodies may with fewer, I. p. 39. n. 199. and fol.
- many Bodies may with one, I. p. 39. n. 197. and fol.
- Air*, II. p. 2. n. 2076. and fol.
- compressed, what Space it takes up, p. 8. n. 2108.
- dilated, what Space it takes up, p. 5. n. 2101. p. 7. n. 2106. and fol. p. 21. n. 2173. and fol.
- is the Vehicle of Sound, p. 49. n. 2319. p. 50. n. 2322. and fol.
- elastic, p. 4. n. 2096. & seq. p. 20. n. 2168. and fol.
- is heavy, p. 2. n. 2084. & seq. p. 19. n. 2163. and fol.
- is a Mixture of various elastic Fluids, p. 10. n. 2122.
- yields to any impression, p. 2. n. 2083.
- in a high Place does not only differ in Density, from the lower Air, p. 11. n. 2123.
- is less dense in a Mountain, than in a Valley, p. 8. n. 2116.
- all can never be taken out by the Air Pump, p. 13. n. 2136. p. 22. n. 2180.
- may be weighed, p. 19. n. 2163. and fol.
- presses equally every way, p. 4. n. 2092. and fol.
- how it may be compressed, p. 28. n. 2216. and fol. p. 32. n. 2231.
- retards the Motion of Fluids, I. p. 381. n. 1592. p. 382. n. 1603. and fol.
- Air*, by pressing upon Bodies, often breaks them, when the Pressure is not every Way equal, II. p. 26. n. 2202. and fol.
- Air* compressed, the various Effects of it, p. 30. n. 2225. and fol. p. 31. n. 2230.
- the Elasticity of it is as the Density, p. 5. n. 2100.
- and Gravity is observed in an Experiment, p. 21. n. 2173.
- the Force of it accurately determined, p. 22. n. 2183. and fol.
- whence it arises, I. p. 22. n. 97.
- the Effects of its Elasticity like those of Gravity, II. p. 9. n. 2115. and fol. p. 31. n. 2229.
- Force of it equal to the Weight of the whole Atmosphere, p. 9. n. 2115. p. 20. n. 2170. and fol.
- Air*, the Motion of it undulatory, p. 43. n. 2271. and fol.
- the undulatory Motion of it communicates a tremulous Motion to the Fibres of Bodies, p. p. 51. n. 2330.
- some Parts of it enter into Water more easily than others. p. 12. n. 2132.
- motion of a Particle of it, p. 42. n. 2273. and fol.
- owing to the Elasticity of the Air, p. 43. n. 2276. and fol.
- is analogous to the Motion of a Pendulum, p. 45. n. 2286. and fol.
- subject to what Law, p. 46. n. 2291. and fol. p. 58. n. 2384.
- in what Time it is made, p. 44. n. 2284. and fol. p. 58. n. 2384.
- with what Velocity the Particles move, p. 62. n. 2389.
- with what Force they fly from one another, p. 8. n. 2111. p. 10. n. 2117.
- what accelerating Force they have, p. 60. n. 2385. and fol.
- the Number of Particles running against the Ear, in what Ratio, p. 62. n. 2388.
- Pressure of it depends upon its height, p. 3. n. 2091.
- sensible Effects of the Pressure of it, II. p. 26. n. 2202. and fol. p. 31. n. 2228. p. 38. n. 2259. and fol.
- Quantities and Elasticities of it after every Motion of the Pistons, make a geometrical Progression, p. 21. n. 2175. and fol.
- Solidity of it demonstrated, I. p. 5. n. 24.
- Wave of, II. p. 43. n. 2271.
- Motion of a Wave, p. 43. n. 2272. and fol.
- Air*,

I N D E X.

- Air*, Velocity of it, *p.* 46. *n.* 2293. and fol.
p. 60. *n.* 2387.
 — greater in Summer than in Winter, *p.* 47. *n.* 2302.
 — when the Waves cease, *p.* 45. *n.* 2289.
Air-pump, II. *p.* 13. *n.* 2136. and fol.
 — single barrel'd one, *p.* 12. *n.* 2158. and fol.
 — in what Air-pumps differ, *p.* 13. *n.* 2138.
 — common ones, *p.* 40. *n.* 2265.
Altitude of the Pole, II. *p.* 307. *n.* 3947.
 — is equal to the Latitude, *p.* 307. *n.* 3947.
 — by what Line determined, *p.* 366. *n.* 4326.
 — of the Stars, *p.* 305. *n.* 3921.
Amplitude of a Cast, I. *p.* 125. *n.* 546.
 — greatest of all, *p.* 126. *n.* 553.
 — how changed, in a different Celerity, *p.* 126. *n.* 552.
 — of the Stars, II. *p.* 305. *n.* 3920.
Angular Motion of a Body in an Ellipse, that moves, I. *p.* 164. *n.* 682.
 — of a Curve, how found, *p.* 164. *n.* 682. and fol.
 — of an Ellipse. See *Ellipse*.
Angle of Incidence, I. *p.* 276. *n.* 1161. II. *p.* 128. *n.* 2784.
 — is equal to the Angle of Reflection, I. *p.* 276. *n.* 1163.
 — mixt, may be diminished in infinitum, *p.* 7. *n.* 34.
 — of a Pendulum. See *Pendulum*.
 — of Reflection, *p.* 276. *n.* 1162.
 — of Refraction, II. *p.* 128. *n.* 2786.
 — when less than the Angle of Incidence, *p.* 128. *n.* 2787. *p.* 130. *n.* 2798.
Angles of Incidence and Refraction have a constant Ratio to one another, *p.* 132. *n.* 2809. and fol. *p.* 247. *n.* 3512.
 — of two Rays, when equal, *p.* 129. *n.* 2790. and fol.
Angles of Incidence and Refraction, Coscants of them, *p.* 132. *n.* 2812. and fol.
Angles, decreasing in infinitum, various Classes of them, I. *p.* 12. *n.* 57. and fol.
Animalcula, the Subtilty of their parts, I. *p.* 8. *n.* 44.
Animal, the greatest Action of, how determined, I. *p.* 429. *n.* 1856.
Animals in compressed Air, II. *p.* 33. *n.* 2237.
 — cannot live without Air, *p.* 35. *n.* 2235. and fol.
Apbelion, II. *p.* 279. *n.* 3701.
- Apfides*, I. *p.* 162. *n.* 674. II. *p.* 279. *n.* 3704.
 Line of the *Apfides*.
 — Determination of the Motion of, I. *p.* 162. *n.* 674. and fol.
Aqueous Humour. See *Humour*.
Archimedes's Problem of mixt Metals, how solved, I. *p.* 374. *n.* 1569. and fol.
Archs of the whole Vibrations of a Pendulum in a Fluid, of what Sort, I. *p.* 457. *n.* 1984. and fol.
Areas described by a Body retained by a centripetal Force, I. *p.* 135. *n.* 585. *p.* 151. *n.* 641.
Arithmetic, mechanical, I. *p.* 44. *n.* 224. and fol.
Ascent of Bodies compared with their Descent, I. *p.* 87. *n.* 396. and fol.
Atmosphere surrounding Glafs. See *Glafs*.
 — of the Earth, II. *p.* 2. *n.* 2080.
Atmosphere of the Earth, its height. *p.* 2. *n.* 2081.
 — how discovered, *p.* 47. *n.* 2303.
 — Effects of its Refraction, *p.* 305. *n.* 3927.
 — its Shadow the Cause of the Eclipses of the Moon, *p.* 297. *n.* 3854. and fol.
 — does not reach to Mars, *p.* 298. *n.* 3859.
Attraction, I. *p.* 16. *n.* 73. II. *p.* 320. *n.* 4052.
 — acts by a simple Application of Parts, I. *p.* 18. *n.* 80. and fol.
 — obtains between the smallest Particles. *p.* 16. *n.* 74 & 76.
 — denotes the Phenomenon, not the Cause, I. *p.* 16. *n.* 73. and fol.
 — is the Cause of Cohesion, I. *p.* 17. *n.* 79.
 — in Fluids, *p.* 16. *n.* 76. and fol.
 — in the Contact of Particles is very great, *p.* 16. *n.* 75.
Attraction changes itself into a repellent Force, *ibid.*
 — is not an occult Quality. *p.* 22. *n.* 98.
 — of the Rays of Light, of what Sort, II. *p.* 116. *n.* 2724. *p.* 127. *n.* 2780. *p.* 133. *n.* 2816.
 — where it obtains, *p.* 131. *n.* 2805.
 — of Glafs on Water. See *Water*.
Attraction of the Rays of Light, the Cause unknown, II. *p.* 121. *n.* 2753.
 — Space of *p.* 131. *n.* 2806.
Auges. See *Apfides*.
Axis in Peritrochio, I. *p.* 51. *n.* 253. *p.* 51. *n.* 256.

Axis

I N D E X.

Axis, in Peritrochio joined to a Screw, *p.* 63. *n.* 304.

- joined to a Pulley, *p.* 63. *n.* 303.
- its Index. See *Index*.
- most perfect Use of it, how determined, I. *p.* 112. *n.* 499. and fol.
- of a Lense, II. *p.* 164. *n.* 3002.
- of a Planet. See *Planet*.
- of the Earth. See *Earth*.

B.

Balance, I. *p.* 36. *n.* 179.

- in æquilibrium, *p.* 38. *n.* 190.
- Axis of, *p.* 37. *n.* 180.
- Center of, *p.* 37. *n.* 181.
- Perfection of it, *p.* 40. *n.* 201.
- its Points of Suspension, *p.* 37. *n.* 182.
- Weight of the Beam of it in all its Parts, how determined, *p.* 249. *n.* 1074.
- deceitful, *p.* 39. *n.* 195.
- Hydrostatical, *p.* 355. *n.* 1480. and fol.
- in which a falling Body raises Weights a little, *p.* 248. *n.* 1072.
- required for nice weighing of Bodies, *p.* 363. *n.* 1522. *p.* 364. *n.* 1524. and fol.

Banks of Rivers. See *Rivers*.

Barometer, II. *p.* 23. *n.* 2184.

Bellows hydrostatical, I. *p.* 350. *n.* 1451.

Black Bodies heat soonest, II. *p.* 274. *n.* 3663 & 3665.

Bladder in compressed Air, II. *p.* 33. *n.* 2238.

Body, every Body is extended, I. *p.* 3. *n.* 13.

— is divisible in infinitum, *p.* 6. *n.* 32. and fol.

— consists of very small Particles, *p.* 15. *n.* 64.

— is heavy, *p.* 31. *n.* 174.

— descending upon an inclined Plane, *p.* 84. *n.* 382. and fol.

— is more difficultly accelerated than moved, *p.* 168. *n.* 707.

— is retarded, *p.* 169. *n.* 714.

— hard in a philosophical Sense, *p.* 15. *n.* 65.

— in the common Sense, *ibid.* *n.* 64.

— elastick, *p.* 21. *n.* 96.

— fluid, *p.* 15. *n.* 68.

— heterogeneous, *p.* 352. *n.* 1461.

— homogeneous, *p.* 352. *n.* 1460.

— soft in a philosophical Sense, *p.* 15. *n.* 67.

— in the common Sense, *p.* 15. *n.* 64.

— falls, if the Center of Gravity is not sustained, *p.* 40. *n.* 206. and fol.

— descends swifter in a Cycloid than in a right Line, *p.* 98. *n.* 455.

— whose Velocity is changed, resists. *p.* 166. *n.* 688.

Body immersed in a Fluid, how much it loses of its Weight, *p.* 355. *n.* 1478. *p.* 357. *n.* 1488. and fol.

— moved in a Cycloid, *p.* 91. *n.* 414.

— resists by its inertia, *p.* 166. *n.* 688. *p.* 167. *n.* 693.

— moved in a Fluid, the Causes of its Resistance, *p.* 436. *n.* 1885. and fol.

— striking against the Scale of a Balance, raises another greater, *p.* 247. *n.* 1071. *p.* 248. *n.* 1073.

— suffers as much as it acts, *p.* 169. *n.* 709. *p.* 193. *n.* 836. and fol.

— presses by its Weight, *p.* 32. *n.* 151.

— projected, moves in a Curve, *p.* 122. *n.* 540. *p.* 123. *n.* 542. *p.* 124. *n.* 544. and fol.

— projected upwards, how long it ascends, *p.* 83. *n.* 378. and fol.

— at rest, resists Motion, *p.* 4. *n.* 19.

— has no Force, *p.* 166. *n.* 692.

— is at rest when the Center of Gravity is sustained, *p.* 40. *n.* 204. and fol. *p.* 41. *n.* 212. and fol.

— resists whilst it acquires Motion, *p.* 80. *n.* 364.

— acts by its innate Force, *p.* 166. *n.* 688.

— one, *p.* 240. *n.* 1041.

Body, the Divisibility of it differs from the Divisibility of Extension, *p.* 6. *n.* 31.

— Weight of it, *p.* 31. *n.* 149.

— its Properties, *p.* 3. *n.* 12. and fol.

Bodies equally hot do not always act in the same Manner upon the same Body, II. *p.* 83. *n.* 2515.

— some grow hot more difficultly than other, *p.* 83. *n.* 2516.

— consists of Parts cohering together by Pressure. See *Pressure*.

— moved in a Fluid rest at last, I. *p.* 453. *n.* 1963.

— all fall equally fast in Vacuo, *p.* 32. *n.* 152. and fol. II. *p.* 36. *n.* 2252. and fol.

Borax, its Density compared with that of Oil. See *Oil*.

Bottom of a River. See *River*.

Box, in which the Heliostate is inclosed, II. *p.* 112. *n.* 2701. and fol.

Box, in which others are inclosed, II. *p.* 122. *n.* 2755. and fol.

Boxes terminated by Glass Planes, *p.* 123. *n.* 2758. and fol.

E e e

Boxes

I N D E X.

Boxes, having spherical Glasses, *p.* 123. *n.* 2761.
Boyle, his Experiment concerning the Ductility of Gold, *I. p.* 8. *n.* 40. and fol.
Bradley determined the Motion of Light, *II. p.* 103. *n.* 2639.
Brasil Pebble, *II. p.* 249. *n.* 3519.
Bulks in Respect of the Densties, *I. p.* 353. *n.* 1464.
 — of Weights and Densties, *ibid. n.* 1466.

C.

Calcination, what, *II. p.* 86. *n.* 2538.
Cameleon, Property of its Eyes, *II. p.* 179. *n.* 3103.
Capillary Tubes, *I. p.* 18. *n.* 82.
 — immersed in Water, attract it, *p.* 23. *n.* 104. and fol.
Cassini endeavoured to determine the Velocity of Light, *II. p.* 99. *n.* 2621.
Cassegrain called himself the Inventor of the Telescope, *II. p.* 230. *n.* 3417.
Cast, Amplitude of it. See *Amplitude*.
 — Direction of. See *Direction*.
Cavity made by repeated Trials, *II. p.* 202. *n.* 848. and fol.
 — is of a determined Magnitude, if it be made by a Body moved with a determinate Velocity, *p.* 201. *n.* 842. and fol.
 — follows the Proportion of the Sum of the Forces lost, *p.* 201. *n.* 841. and fol. *p.* 208. *n.* 872.
Cavity, the Formation of one, of what Sort, *p.* 200. *n.* 840.
Cavities made by Bodies striking against soft Bodies, of what Sort, *p.* 195. *n.* 825. and fol.
 — made in soft Bodies, how measured, *p.* 268. *n.* 975.
 — in soft Bodies, in what Time made. See *Times*.
 — do not differ when the Heights are inversely as the Masses, *p.* 198. *n.* 834.
 — are sometimes to one another in a Ratio compounded of the Masses of the and the Squares of the Velocities, *p.* 201. *n.* 845. and fol.
Causes retarding a spouting Fluid, *I. p.* 380. *n.* 1589. and fol.
Caustick Lines, the Points of them how discovered, *II. p.* 213. *n.* 3314. and fol. *p.* 217. *n.* 3340. and fol.
Celerity. See *Velocity*.
Central Force, sometimes causes a Body to describe a Circle. See *Circle*.
 — sometimes causes a Body to describe an Ellipse. See *Ellipse*.

Central Force, sometimes causes a Body to describe various Curves, *I. p.* 147. *n.* 624. and fol.
Central Force, a Body may by it describe a Curve moveable about the Center of the Forces, *I. p.* 159. *n.* 661. *p.* 160. *n.* 665. and fol.
Central Forces, *I. p.* 129. *n.* 564.
 — of the same Nature with Gravity, what Effect they produce upon unequal Bodies, *p.* 147. *n.* 623. and fol.
Central Forces compared together, of what Sort? *I. p.* 146. *n.* 618. and fol.
 — are of great Use in Physicks, *p.* 129. *n.* 566.
 — the Ratio they have one to another, how determined, *p.* 147. *n.* 620.
 — the Causes of their Differences, *p.* 163. *n.* 591.
 — are sometimes in an inverse Ratio of the Squares of the periodical Times, *p.* 145. *n.* 616. and fol.
 — in an inverse Ratio of the Squares of the Distances, *p.* 147. *n.* 621. and fol. *p.* 153. *n.* 655.
 — as the Quantities of Matter, *p.* 141. *n.* 605. and fol.
 — as the Distances from the Center, *p.* 143. *n.* 607. and fol. *p.* 153. *n.* 654.
 — in a Ratio compounded of the Quantities of Matter and Distances, *p.* 143. *n.* 609. and fol.
 — when they are equal, *p.* 144. *n.* 611. and fol.
Centrifugal Force, *I. p.* 128. *n.* 562.
 — is encreased according to the Quantity of Matter, *p.* 135. *n.* 588. and fol.
 — is always equal to the centripetal Force, *p.* 129. *n.* 565.
Centrifugal Force, a Body moved by it endeavours to recede in the Tangent to the Curve, *p.* 128. *n.* 561.
 — on a Plane begins to recede along the Curve that passes through the Center of the Plane, *p.* 133. *n.* 579. and fol.
Centripetal Force, *p.* 129. *n.* 563.
 — is a Pressure acting upon a Body, *p.* 135. *n.* 587.
 — is given, when the Areas described are proportional to the Times, *p.* 135. *n.* 586. *p.* 151. *n.* 642.
 — is diminished with the Quantity of Matter, *p.* 135. *n.* 588. and fol.
 — is always equal to the centrifugal Force, *p.* 129. *n.* 565.
Centripetal Force, a Body in Motion retained by it, describes a Curve, *p.* 128. *n.* 560.
Centri-

I N D E X.

- Centripetal* Force, how a Body endeavours to recede from this Curve, *p.* 128. *n.* 561.
- Centripetal* Force, a Body in Motion retained by it, what kind of Areas it describes. See *Area*.
- according to what Laws such a Body is moved, *p.* 152. *n.* 648.
- in what plane it is moved, *p.* 133. *n.* 581. *p.* 151. *n.* 640.
- Center* of the Action of Powers, I. *p.* 48. *n.* 246.
- of Gravity, *p.* 40. *n.* 202. *p.* 41. *n.* 213.
- is demonstrated to be given, *p.* 42. *n.* 214. and fol.
- how investigated, *p.* 42. *n.* 216. and fol.
- of Bodies joined how moved, *p.* 105. *n.* 476. and fol.
- of any Bodies whatsoever can either rest, or go uniformly in a right Line, *p.* 301. *n.* 1232.
- when it is at Rest, *p.* 299. *n.* 1223. and fol. *p.* 303. *n.* 1243. and fol.
- in a Ship is sometimes at rest, *p.* 300. *n.* 1227. and fol. *p.* 303. *n.* 1245. and fol.
- of a Balance. See *Balance*.
- of Oscillation, *p.* 93. *n.* 425.
- at what Distance from the Point of Suspension in a right Line, *p.* 93. *n.* 427.
- how determined, *p.* 104. *n.* 471. and fol. *p.* 251. *n.* 1077.
- in Machines how determined, *p.* 117. *n.* 522. and fol.
- of Percussion, *p.* 242. *n.* 1050.
- Coincides with the Center of Oscillation, *p.* 242. *n.* 1051. *p.* 252. *n.* 1078. and fol.
- Center* of Gravity, its motion examined, *p.* 299. *n.* 1223. and fol.
- common, *p.* 301. *n.* 1234.
- the same before and after the stroke, *p.* 303. *n.* 1242.
- is not changed, if the bodies run against one another directly, *p.* 303. *n.* 1245. and fol. *p.* 306. *n.* 1252. and fol.
- of Gravity, its Motion is not changed in the oblique Concourse of two Bodies, *p.* 304. *n.* 1248.
- sometimes is not changed, although the Motions of the Bodies be changed, *p.* 302. *n.* 1238. and fol.
- Of Oscillation determined in the Axis in Peritrochio. *p.* 117. *n.* 526. and fol.
- in the Pulley *p.* 119. *n.* 530. and fol.
- Center* in the Lever, *p.* 117. *n.* 522. and fol.
- of Percussion, its Property, *p.* 252. *n.* 1078.
- Change* of Force. See *Force*.
- Channels* of Rivers. See *River*.
- Chord* stretched, if it be put in Motion, sometimes communicates Motion to another Chord, II. *p.* 56. *n.* 2372. and fol.
- sometimes is at rest in the Middle, *p.* 57. *n.* 2375.
- in two Points, *p.* 57. *n.* 2376.
- Chord*, Elasticity of. See *Elasticity*.
- Sagitta of it. See *Sagitta*.
- Chords* of the same Length and Tension are bent by equal Forces, I. *p.* 316. *n.* 1290.
- of Catgut not to be considered as Fibres, *p.* 314. *n.* 1278.
- Chords* of Metal, the Proportions of their Lengthenings how determined, *p.* 315. *n.* 1282. and fol.
- Choroides*, II. *p.* 174. *n.* 3068.
- Circle*, generating, I. *p.* 90. *n.* 409.
- may be described by a body moved with a Central Force, *p.* 148. *n.* 627. *p.* 149. *n.* 634. *p.* 150. *n.* 638. *p.* 152. *n.* 649. and fol.
- Circles*, the Ratio of their Surfaces to the Squares of their Diameters, *p.* 13. *n.* 63.
- Classes* to which Bodies acting differently upon Light may be referred, II. *p.* 136. *n.* 2830, *p.* 137. *n.* 2834. and fol.
- of Infinites. See *Infinites*.
- Clay*, what Sort it ought to be, that its Parts may be easily pressed inwards, I. *p.* 94. *n.* 821. and fol.
- Clouds*, how caused, II. *p.* 86. *n.* 2543.
- their Colours, *p.* 276. *n.* 3682.
- Two small ones in the Heavens, *p.* 317. *n.* 4040.
- Cocks*, the Ratio of different ones to one another, how explored, I. *p.* 439. *n.* 1905.
- Cohesion* of two leaden Balls, I. *p.* 18. *n.* 81.
- of Parts, *p.* 15. *n.* 69.
- to be attributed to Attraction, *p.* 17. 6. 79.
- in Fluids illustrated by Experiments, *p.* 397, *n.* 1661. and fol.
- sometimes retards the Motion of Fluids, *p.* 378. *n.* 1583.
- accelerates the Motion of Fluids, *p.* 394. *n.* 1651. and fol. *p.* 396. *n.* 1659.
- of a Fluid, is the first cause of the

I N D E X.

Earth, its Elevation at the Equator determined, *p.* 365, *n.* 4314, *p.* 365, *n.* 4322.

— Figure of it, *p.* 364, *n.* 4309, and fol.

— determined, *p.* 393, *n.* 4413, and fol.

— on the Surface of it, the Degrees encrease the nearer you go to the Poles, *p.* 366, *n.* 4329.

— Motion of, *p.* 281, *n.* 3729, *p.* 282, *n.* 3740, and fol. *p.* 333, *n.* 4136, and fol.

— Effects of its Motion about its Axis, *p.* 300, *n.* 3876, and fol.

— Phænomena of, according to the different Situation of a Spectator on its Surface, *p.* 303, *n.* 3906, *p.* 307, *n.* 3944, and fol.

— the Surface of it is unequal, I. *p.* 402, *n.* 1683.

Eastern Part *n.* II. *p.* 304, *n.* 3915.

East, Point of, *p.* 304, *n.* 3918.

Echo. See *Sound*.

Eclipse of the Moon. See *Moon*.

— of a Satellite, II, *p.* 294, *n.* 3825.

— Of the Sun. See *Sun*.

Eclipses, Line of, *p.* 288, *n.* 3782.

Ecliptick Plane of, *p.* 279, *n.* 3707.

— Poles of, *p.* 289, *n.* 3790.

— Beginning of, *p.* 288, *n.* 3785.

Effect of an Action against an Obstacle, in what Ratio, I. *p.* 169, *n.* 709.

— great of a Machine, *p.* 110, *n.* 491.

— of Force, *p.* 166, *n.* 690, *p.* 168, *n.* 708.

— When a Body strikes against a soft Body, *p.* 195, *n.* 825.

Effects of Forces reduced to a Measure, *p.* 193, *n.* 819, *p.* 194, *n.* 821.

— sometimes are in a Ratio compounded of the Masses, and Squares of the Velocities, *p.* 193, *n.* 818, and fol.

Eighth or Diapason, *p.* 55, *n.* 2362.

Elastick Force. See *Force*.

Elastick, equal Bodies, when they are carried towards the same Part, continue their Motion with changed Velocities, I. *p.* 262, *n.* 1120, and fol.

— when they are carried towards contrary Parts, they go back with changed Velocities, I. *p.* 262, *n.* 1120, *p.* 263, *n.* 1123, and fol.

— if one strikes against another at rest, and the Velocities be charged, what happens, *p.* 263, *n.* 1125, and fol. of what Parts they consist, *p.* 314, *n.* 1278.

— striking against a fixed Obstacle, return with the same Velocity, with which they came, *p.* 254, *n.* 1086.

— in a ship, if they run against one ano-

ther, with what Velocities they return, *p.* 259, *n.* 1107, and fol. are separated after the Stroke, *p.* 217, *n.* 930.

— if they run against one another directly, sometimes they both return with the same Velocity, which they had before the Stroke, *p.* 257, *n.* 1100, and fol.

— if three concur, with what Action they are separated, *p.* 288, *n.* 1194, *p.* 295, *n.* 1217, and fol.

Elastick Bodies, their mutual Action illustrated, *p.* 267, *n.* 1137, & fol.

— Restoration of their Figure, what it produces, *p.* 266, *n.* 1134.

— Velocities of, after the Stroke, by what Laws determined. See *Laws*.

Elasticity, I, *p.* 21, *n.* 96.

— of Air. See *Air*.

— of a Chord is of the same Kind with Gravity, *p.* 316, *n.* 1292.

— of Fibres, whence produced, *p.* 314, *n.* 1279.

— of Plates is examined, *p.* 324, *n.* 1322, and fol.

Elasticity imperfect, *p.* 254, *n.* 1084.

— perfect, *p.* 253, *n.* 1083.

— communicates a greater Velocity, *p.* 329, *n.* 1350, *p.* 332, *n.* 1363, and fol.

Elasticity, Diversity of it in Bodies of the same Kind, upon what it depends, *p.* 323, *n.* 1321.

— the Laws of it how explored, *p.* 320, *n.* 1304, and fol.

Electricity, II, *p.* 72, *n.* 2453.

Electricity, the Action of it ceases in Vacuo, *p.* 76, *n.* 2469, *p.* 76, *n.* 2474.

— Cause of it and Fire have a Relation one to the other, *p.* 72, *n.* 2454, and fol.

— various Effects of it, *p.* 72, *n.* 2455, and fol. *p.* 74, *n.* 2463, and fol.

— in Glass, the Cause of it, *p.* 76, *n.* 2471, and fol.

Ellipsis, sometimes described by the central Force of a Body in Motion, I. *p.* 147, *n.* 626, *p.* 148, *n.* 633, *p.* 149, *n.* 637, *p.* 154, *n.* 656, and fol.

— a moveable one may be described by a Body in Motion, *p.* 148, *n.* 630, and fol. *p.* 149, *n.* 635, and fol. *p.* 160, *n.* 668, and fol.

Ellipse, Description of it, *p.* 147, *n.* 625.

— angular Motion of it, *p.* 162, *n.* 674, and fol.

— some Properties of it, II. *p.* 367, *n.* 4339, and fol.

Elongation of the Planets, II. *p.* 290, *n.* 3797.

— greatest, *p.* 290, *n.* 3798.

Error,

I N D E X.

Error of many who compare Machines together, I, p. 115, n. 516.
Evaporation, what, II. p. 86, n. 2538.
Evening. See *Twilight*.
Excentricity of the Planets, II. p. 279, n. 3698.
Exhalation, what, II. p. 86, n. 2538.
Exhalations, are set on Fire by the Sun's Rays, p. 89, n. 2562.
 — and by the Mixture of various Exhalations, p. 89, n. 2562, and fol.
Exhalations set on Fire in the Air produce fiery Meteors, p. 89, n. 2566.
 — inflammable consist of the Food of Fire, 89, n. 2560.
 — some contain Fire, p. 87, n. 2546.
Extension to be first considered in Body, I. p. 3, n. 13.
Extended, every thing that is so, is not Body, I, p. 3, n. 13.
Extinction of Fire. See *Fire*.
Eye artificial, II. p. 166, n. 3015.
 — changes, that Vision may not be confused, p. 177, n. 3089, and fol.
Eyes of short sighted People, the Fault of them here corrected, p. 185, n. 3144.
 — Fault of old Men's, how corrected, p. 185, n. 3139.
Eyes, why an Object seen with both Eyes appears single, p. 178, n. 3102, and fol.
 — when an Object appears double, p. 179, n. 3105.

F.

Fibre, lengthening of. See *Lengthening*.
Fibres, Elasticity of. See *Elasticity*.
 — depends upon their Tension, I. p. 314, n. 1280.
 — is destroyed if the Fibres be stretched with too much Force, p. 314, n. 1281.
Fifth, or Diapente, II. p. 55, n. 2363.
Figurable, Body is, I, p. 4, n. 20.
Fire is attracted by Bodies, II. p. 63, n. 2399.
 — is found in all known Bodies, p. 63, n. 2399, p. 71, n. 2452, and fol.
 — joins itself to Bodies, p. 63, n. 2897.
 — penetrates into all Bodies, p. 63, n. 2396.
 — but not with equal Ease, p. 63, n. 2400, p. 83, n. 2516, p. 84, n. 2520.
 — more easily penetrates into a hotter Body, p. 84, n. 2521, and fol.
 — is extinguished, though the Food of it remains, p. 93, n. 2582.
 — and when Air is absent, p. 93, n. 2583, and fol.
Fire, that it may not be extinguished, there

are required some particular Particles, p. 93, n. 2586, and fol.
 — when enclosed every way, is soon extinguished, p. 94, n. 2589, and fol.
 — why extinguished by Water, p. 95, n. 2593, and fol.
 — in Bodies, is retained by circumambient Bodies, p. 64, n. 2401, p. 84, n. 2526, and fol.
 — what Parts it separates in Combustion, p. 87, n. 2547, and fol.
 — entering into a Body, acts upon the Fire contained in the Body, p. 85, n. 2531, and fol.
 — may have a very swift Motion, p. 64, n. 2402.
 — does not alter the Particles of Water to which it adheres, p. 86, n. 2542.
 — always turns the Bodies into a Fluid, whose Parts it separates, p. 86, n. 2537.
 — moved in different Lines, excites the greater Heat, p. 65, n. 2415.
 — how it acts upon Bodies calcined, to dissolve them, p. 90, n. 2567, and fol.
 — carries along with the Parts of Bodies separated in Exhalations, p. 86, n. 2541.
 — where it is said to be, p. 63, n. 2393.
 — contained in Glass is more easily moved in Vacuo, p. 74, n. 2463, p. 76, n. 2473.
 — does not want Air to make it appear, p. 79, n. 2486, and fol.
Fire, by the Action of it, Bodies are dilated, p. 64, n. 2403, p. 67, n. 2426, and fol.
 — and make an Elastick Fluid, p. 64, n. 2404.
 — the more subtile Parts of Bodies, penetrate into Bodies, p. 64, n. 2407, p. 90, n. 2569.
 — the Particles of Bodies acquire an Elastick Force, p. 69, n. 2440, and fol.
 — a repellent Force, p. 68, n. 2436.
 — the Weight of Bodies is sensibly increased, p. 90, n. 2570.
 — Extinction of it, p. 93, n. 2581.
 — the Motion of it triple, p. 82, n. 2500, and fol.
Fire, continues in Motion, till the Degrees of Heat are equal, p. 82, n. 2505.
 — if it moves more difficultly towards some Parts, its Motion is increased towards others, p. 85, n. 2530.
 — the intimate Nature of it is unknown, p. 63, n. 2392.
 — Food of it
 — Weight of it not sensible, p. 64, n. 2408, p. 99, n. 2571, and fol.
 — Tokens of its Presence, p. 63, n. 2393, p. 65, n. 2419, and fol. p. 67, n. 2425.

Fire

I N D E X.

- Fire* consumes Bodies in Vacuo, but without Flame, *p.* 91, *n.* 2576, and fol.
- Fish*, some cannot live without Air, II. *p.* 33, *n.* 2236.
- Flame*, how caused, II, *p.* 87, *n.* 2553.
- why pyramidal in the Air, *p.* 88, *n.* 2555.
- would be cylindrical, if the lateral Diffipation were set aside, *p.* 88, *n.* 2556, and fol.
- Flamsteed* observed, that Saturn disturbs the Motion of Jupiter's Satellites, II. *p.* 321, *n.* 4063.
- Flints* transparent divide an homogeneous Ray into two in Refraction, II. *p.* 248, *p.* 3518, and fol.
- Fluidity* all depends upon Heat, II. *p.* 68, *n.* 2438.
- whence it arises, I, *p.* 340, *n.* 1409.
- Fluid* Body, I. *p.* 15, *n.* 68.
- ascends towards the Bodies, which attract it, *p.* 20, *n.* 91.
- is hollowed, when repelled, *ibid.*
- acquires the Weight which an immersed Solid loses, *p.* 359, *n.* 1503, and fol.
- contains sometimes at the Bottom a Body lighter than itself, *p.* 363, *n.* 1518, and fol.
- elastick is produced by a cold Effervescence, II. *p.* 70, *n.* 2443, and fol.
- Fluid* elastick, how and what Sort of one is separated from Water, II, *p.* 11, *n.* 2129, and fol. *p.* 24, *n.* 2194, and fol.
- is more heavily pressed, by a lighter floating on the Top of it, I, *p.* 343, *n.* 1426, and fol.
- in a Tube, by what Action removed or retarded, *p.* 418, *n.* 1785, and fol.
- ascends to the same Height in any communicating Tubes whatsoever, *p.* 342, *n.* 1422, and fol.
- descends faster out of a Vessel, that has a Tube joined to it, *p.* 394, *n.* 1652, and fol.
- moved through a Tube, what lateral Pressure it exerts upon it, *p.* 418. *n.* 1781. and fol. *p.* 422, *n.* 1807. and fol.
- in what Time it goes or comes in a Cylindrick curve Tube, *p.* 411. *n.* 1749. and fol.
- is moved with the same Celerity, at what Part soever the Pressure is taken away, *p.* 376, *n.* 1574.
- presses according to the Ratio of the Height, and not the Quantity, *p.* 347, *n.* 1441, and fol. *p.* 350, *n.* 1453.
- presses upwards and downwards with the same force, *p.* 349, *n.* 1448, and fol. *p.* 351, *n.* 1457.
- laterally as well as vertically, *p.* 348, *n.* 1445, *p.* 349, *n.* 1447.
- by pressure acquires velocity, *p.* 376. *n.* 1575, and fol.
- pressed by a super-incumbent Fluid, with what Velocity it spouts out of a Hole, *p.* 378, *n.* 1583, *p.* 378. *n.* 1584, and fol.
- the less it is compressed, the less Action of Fire causes it to boil, II, *p.* 85, *n.* 2534. and fol.
- spouting may be considered as several Solids following one another, I. *p.* 383, *n.* 1612.
- rises higher, when its Direction is a little inclined to the Horizon, *p.* 381, *n.* 1594. and fol. *p.* 383, *n.* 1612.
- what to be observed, to make it spout higher, *p.* 381, *n.* 1594, and fol. *p.* 381. *n.* 1599, and fol. *p.* 382, *n.* 1606, and fol.
- can only spout to a certain Height, *p.* 383, *n.* 1611, and fol.
- Fluid*, when it spouts to the greatest distance of all, *p.* 388. *n.* 1621, and fol.
- with what Velocities it goes out of different Holes, *p.* 379, *n.* 1586. and fol.
- sometimes it sustains a Body specifically heavier than the Fluid, *p.* 360, *n.* 1506, and fol.
- spouting vertically, how high it rises, *p.* 380, *n.* 1588, and fol.
- moves very fast, whilst it descends vertically, *p.* 394. *n.* 1651. and fol.
- Fluid*, the Action of it is Pressure, *p.* 437. *n.* 1893.
- its Action upon a Body lighter than itself, which is retained, is the same as upon a Body heavier than the Fluid, *p.* 361, *n.* 1512, and fol.
- upon the Bottom and Sides of a Vessel containing it, encreases with the Height of the Fluid, *p.* 344, *n.* 1430, *p.* 347, *n.* 1441, and fol. *p.* 350. *n.* 1453, and fol.
- the Action of a Fluid moved against an Obstacle at rest, of what Kind, *p.* 414, *n.* 1760, and fol.
- and against an Obstacle moved with the Fluid, of what Kind, *p.* 417. *n.* 1777.
- when greatest, *p.* 417, *n.* 1778, and fol.
- the Impetus of a Fluid in Motion is its Pressure, *p.* 414, *n.* 1759.
- a Quantity of one flowing cannot be determined from the Velocity being known, *p.* 389, *n.* 1631.
- Quantity of a Fluid flowing out of Vessels, of what Kind, *p.* 388, *n.* 1625. and fol.

Fluid,

I N D E X.

- Fluid* a greater Quantity will run out, if the lower Aperture of the Tube, through which it passes, be encreased, *p.* 396. *n.* 1658, and fol.
- the Quantities going out of equal Holes, in what Ratio, *p.* 390, *n.* 1635.
- Quantities running out of different Holes, in what Ratio, *p.* 391, *n.* 1638, and fol.
- the Particles of a Fluid running out, acquire their whole Velocity, in a very short Time, *p.* 377, *n.* 1579, and fol.
- the first Particles that go out don't move slower than the following ones, *p.* 376, *n.* 1576, and fol.
- Fluid*, the lower Particles of one, how pressed by those above them, *p.* 341, *n.* 1414, and fol.
- Retardation of one in a Tube, in the Ingress and Egress, of what Sort, *p.* 422, *n.* 1806.
- Surface of, why flat, *p.* 341, *n.* 1413.
- Fluids* are dilated by Heat, II, *p.* 67, *n.* 2428, and fol.
- consist of Particles of the same Nature with those of other Bodies, I, *p.* 340, *n.* 1410.
- in what they agree with solid Bodies, *p.* 3400, *n.* 1411.
- some are not reduced into a less Space by Compression, II, *p.* 1, *n.* 2074.
- are elastick, *p.* I, *n.* 2075, *p.* 10, *n.* 2118, and fol.
- elastick, various, how produced, *p.* 10, *n.* 2119, and fol. *p.* 34, *n.* 2239.
- Fluids*, their Densities. See *Density*.
- elastick, their Particles don't touch one another, *p.* 12, *n.* 2135.
- in Motion, their lateral Action examined, I, *p.* 418, *n.* 1780, and fol.
- their Impetus examined, *p.* 414, *n.* 1758, and fol.
- all their Particles are at rest, *p.* 342, *n.* 1421.
- Focus* of Rays, II, *p.* 144, *n.* 2875.
- when at a less Distance, *p.* 144, *n.* 2877.
- imaginary, *p.* 144, *n.* 2876.
- Foot* Royal of *France*, its Proportion to the *Rhinland*, I, *p.* 398, *n.* 1664.
- Foot* cylindrick of Water, Weight of it, *p.* 449, *n.* 1944.
- Cubic, of Water, its Weight, *p.* 369, *n.* 1551, *p.* 449, *n.* 1944.
- Force*, I, *p.* 167, *n.* 694.
- accelerating that acts upon the Particles of Air, II, *p.* 60, *n.* 2385, and fol.
- lost of a Body moved in a Fluid, from the Resistance from the first Cause, proportional to the Space run through, I, *p.* 453, *n.* 1960.
- how determined from the Effects, *p.* 231, *n.* 1002.
- in the direct Concourse of three Bodies, *p.* 285, *n.* 1183, *p.* 293, *n.* 1213.
- in the direct Percussion of several Bodies joined, *p.* 243, 1056.
- acquired in falling, *p.* 178, *n.* 754.
- Centrifugal. See *Centrifugal*.
- Centripetal. See *Centripetal*.
- destroyed, its Ratio to the Change of Force in Collision, *p.* 237, *n.* 1024.
- in Collision, with a given Velocity, determined, *p.* 245, *n.* 1062.
- in a Stroke in the Collision of three Bodies, *p.* 284, *n.* 1179.
- how determined, *p.* 228, *n.* 985, and fol. *p.* 234, *n.* 1009, *p.* 245, *n.* 1063.
- is the same, if the respective Velocity is the same, *p.* 222, *n.* 956, and fol.
- differs from Pressure, *p.* 169, *n.* 714, and fol.
- elastick sometimes is communicated by the Action of Fire, II, *p.* 69, *n.* 2440, and fol.
- and from other Causes, *p.* 70, *n.* 2448.
- generated by Pressure, I, *p.* 167, *n.* 696, and fol.
- and Inertia differ relatively, *p.* 166, *n.* 691.
- in the Collision of Bodies, what destroyed. See *Collision*.
- in the Collision of three Bodies, two of which are carried one Way, and the third the other Way, of what Kind, *p.* 284, *n.* 1181, and fol. *p.* 293, *n.* 1212.
- Force* bending, *p.* 316, *n.* 1286.
- what Ratio it bears to the stretching Force, *p.* 316, *n.* 1287.
- innate, *p.* 4, *n.* 18, *p.* 78, *n.* 356.
- is not altered unless by an extraneous Action, *p.* 78, *n.* 356.
- a less sometimes prevails before a greater, *p.* 227, *n.* 980, and fol.
- does not always follow the Proportion of the Square of the Velocity, *p.* 274, *n.* 1158.
- none lost in the Collision of elastick Bodies, *p.* 254, *n.* 1084, and fol.
- never immediately destroys Force, *p.* 218, *n.* 937, and fol.
- may be diminished by Pressure, *p.* 168, *n.* 708.
- whereby a certain Celerity is communicated in compound Motion, how determined, *p.* 273, *n.* 1156, and fol.

I N D E X.

- Force*, which detains a Body in a Circle, *p.* 152, *n.* 649, and fol.
- refracting is sensibly as the Density, II. *p.* 136, *n.* 2831.
- repellent is communicated to Particles by the Action of Fire, *p.* 68, *n.* 2436.
- resolved, cannot be again so resolved, that each of them will be proportional to the Squares of the Velocities, I, *p.* 274, *n.* 1159.
- exceeds Pressure, *p.* 168, *n.* 701.
- is equal to the Action of the Pressure, which communicated it, *p.* 167, *n.* 700.
- Force*, the infinitely small Change of it, in what Ratio, *p.* 240, *n.* 1039, and fol.
- Force* innate, Body acts by it. See *Body*.
- Forces* absolute when communicated by the moving Cause, which itself also is moved, what happens, *p.* 268, *n.* 1139.
- acquired in falling, when equal, *p.* 187, *n.* 790, *p.* 198, *n.* 834.
- Central. See *Central*.
- Of Bodies themselves on Light, how discovered, II. *p.* 141, *n.* 2859, and fol.
- Forces* impressed by a bent Spring, of what Kind, I. *p.* 254, *n.* 1087, and fol. *p.* 257, *n.* 1096, and fol.
- innate of Bodies in Motion, of what Kind, *p.* 177, *n.* 757, *p.* 182, *n.* 778, and fol.
- whole bending Plates, are in a duplicate Ratio of the Bendings, *p.* 327, *n.* 1341.
- if lost, what is the Effect, *p.* 193, *n.* 818, and fol.
- are proportional to the Effects, *p.* 169, *n.* 709, and fol. *p.* 199, *n.* 836, and fol.
- oblique demonstrated, *p.* 50, *n.* 252.
- of Pendulums. See *Pendulums*.
- which equally lengthen Fibres equally long, are not as the Quantities of Matter in the Fibres, *p.* 323, *n.* 1320.
- which are consumed in making equal Cavities, are equal, *p.* 196, *n.* 826, and fol.
- whereby Parts of the Segments of Spheres are pressed inwards, of what Sort *p.* 336, *n.* 1391.
- whereby Bodies are struck, of what Sort, *p.* 336, *n.* 1392.
- all the Particles act upon Light, how compared, *p.* 140, *n.* 2853.
- are equal if the Squares of Velocities are inversely as the Masses, *p.* 179, *n.* 758, *p.* 184, *n.* 785, and fol. *p.* 200, *n.* 838.
- are sometimes as the Masses, *p.* 177, *n.* 748.
- sometimes as the Squares of the Velocities, *p.* 178, *n.* 753, *p.* 450, *n.* 1948.
- sometimes as the Velocities, *p.* 187, *n.* 791.
- Forces*, their Actions, *p.* 193, *n.* 817, and fol.
- Comparison of them, *p.* 177, *n.* 747, and fol.
- Decrements in Collision, of what Kind, *p.* 224, *n.* 965.
- Destruction of, *p.* 193, *n.* 817, and fol.
- Effects of, brought to a Measure. See *Effects*.
- must be unequal, that unequal Bodies concurring may be at Rest, *p.* 225, *n.* 968, and fol.
- innate of elastick Bodies, their Sum after the Stroke is equal to the Sum of the Forces before the Collision, *p.* 254, *n.* 1085, *p.* 266, *n.* 1135, and fol.
- Measure of, how discovered, *p.* 273, *n.* 1152.
- Changes of in Collision, happening in certain Times examined, *p.* 239, *n.* 1037, and fol.
- during the Collision demonstrated geometrically, *p.* 236, *n.* 1016, and fol, *p.* 266, *n.* 1134.
- in an Instant are to one another as the Velocities of the Bodies, *p.* 237, *n.* 1023.
- the Nature, Generation, and Destruction of them, *p.* 166, *n.* 688, and fol.
- whereby the Particles of Bodies act upon Light, their Proportions how determined, II, *p.* 137, *n.* 2837, *p.* 142, *n.* 2862, and fol.
- the Sum of, before and after the Stroke of what Sort, whether elastick Bodies carried in different Directions, run directly against a third at the same Time, I, *p.* 291, *n.* 1203, *p.* 298, *n.* 1221.
- in the Collision of three Bodies, which are at rest after the Stroke, *p.* 284, *n.* 1180.
- diminished, if a Body runs against another, *p.* 217, *n.* 932.
- of what Kind, if two Bodies are at rest after the Stroke, *p.* 223, *n.* 960, and fol. *p.* 234, *n.* 1009.
- when in Percussion several Bodies joined are at rest after the Stroke, *p.* 244, *n.* 1057, and fol.
- Fountain* Hero's, *p.* 40, *n.* 2268, and fol.
- Fourth*, or Diatesferon, II, *p.* 55, *n.* 2364.
- Friction* to be overcome by the Power in a Machine, I, *p.* 58, *n.* 284.
- in Screws, *p.* 58, *n.* 285.
- retarding a spouting Fluid, how to be diminished, *p.* 381, *n.* 1596, and fol.
- Full Moon*, II, *p.* 296, *n.* 3839.
- Fusion*, what, *p.* 86, *n.* 2538.

I N D E X.

G.

Generating Circle. See *Circle*.
Glass attracts Water, I, p. 22, n. 99, and fol.
 — rubbed, why it emits Fire, II, p. 76, n. 2472.
 — burning, p. 170, n. 3051, and fol.
Glass, the Surface of it surrounded with a certain Atmosphere, p. 76, n. 2471.
Glasses, of Use in Vision. See *Vision*.
Glasses, the Consideration of their Surfaces affords six Classes, p. 164, n. 2968, and fol.
Globe of Glass, put in Water goes toward the Sides of the Vessel, I, p. 21, n. 92.
 — goes towards the Middle, if the Vessel be over-filled, p. 21, n. 93.
Globes of Iron, laid upon Mercury, approach one another, p. 21, n. 94.
 — of Glass, laid on Water, come towards one another, p. 21, n. 92.
Gold, its Density. See *Density*.
 — Ductility, I, p. 8, n. 41, and fol. p. 13, n. 63.
 — specifick Gravity compared with that of Water, p. 369, n. 1509.
 — Bulk compared with that of Silver, p. 13, n. 63.
 — Gravity, I, p. 31, n. 148, II, p. 320, n. 4051.
 — acts upon Bodies in Motion, as in those at rest, I, p. 82, n. 371.
 — does not communicate equal Degrees of Force to a Body, p. 178, n. 755.
 — destroys Motion in an ascending Body, p. 83, n. 377.
 — is universal, II, p. 319, n. 4047.
 — in a Fluid, why not sensible, I, p. 340, n. 1411.
 — of Particles is preserved in a Fluid, p. 340, n. 1411.
 — on a Sphere, II, p. 325, n. 4082, p. 327, n. 4100, and fol.
 — not every where the same, p. 366, n. 4333, and fol.
 — decreases, as you recede from the Center of the Earth, p. 322, n. 4075.
 — diminished under the Æquator, p. 364, n. 4310.
 — as you recede from the Pole, p. 336, n. 4149.
 — mutual of Bodies is not sensible near the Earth, p. 321, n. 4068.
 — under the Æquator, p. 324, n. 4080, p. 367, n. 4336.
 — under the Pole, p. 324, n. 4080, p. 366, n. 4333, and 4335, and fol.
 — does not follow from any thing known to us, p. 327, n. 4099.

— proved, p. 320, n. 4054, and fol.
 — in various Cases, p. 325, n. 4083.
 — respective, I, p. 357, n. 1491, and fol.
 — specifick of a Body, p. 352, n. 1462.
Gravity, the Action of it upon all Bodies the same, p. 32, n. 155.
 — Center of. See *Center*.
 — Determination of in different Places, II, p. 377, n. 4432, and fol.
 — Laws of its Diminution, p. 372, n. 4393, and fol.
 — Diversity of, measured by Pendulums, I, p. 94, n. 431, and fol.
 — Laws of it, II, p. 319, n. 4048, and fol. p. 321, n. 4066, and fol.
 — common Center of Gravity of the Moon and Earth, p. 387, n. 4510.
Gravity, Phænomena of it, I, p. 31, n. 147, and 149, p. 32, n. 152.
Gravities, on the Surfaces of the Planets, II, p. 339, n. 4166.
 — of the Earth and Moon, p. 387, n. 4509.
 — Specifick and Densities, in homogeneous Bodies, I, p. 353, n. 1463.
Gregory, his Telescopes. See *Telescopes Catoptric*.

H.

Halley, defends the Opinion of *Romer*, II, p. 101, n. 2631.
Hardness, I, p. 15, n. 70.
Heat in a hot Body, what, II, p. 64, n. 2409, with Respect to us, p. 65, n. 2410.
 — conceived sooner by some Bodies than others, p. 274, n. 3664.
 — is equably dispersed thro' the whole Mass of a Body, p. 82, n. 2509.
 — and Bodies near one another, p. 82, n. 2510, and fol.
 — intimately joined with Light in the Sun's Rays, p. 66, n. 2421.
 — not discovered in the Moon's Light, p. 66, n. 2423.
 — and Light, uncertain whether they are ever separated, p. 65, n. 2416, and fol.
 — to be attributed to the same Cause, p. 63, n. 2395.
 — longer preserved by Bodies, which grow hot more difficultly, p. 84, n. 2524.
 — preserved longest by the central Parts of Bodies, p. 84, n. 2525.
 — retained by Air in Water, p. 84, n. 2527, and fol.
 — does not follow the Proportion of the Quantity of the Fire, p. 83, n. 2517, and fol.
 — when it changes a Solid into a Fluid, p. 68, n. 2435, and fol.

I N D E X.

- Heat*, Causes of it in the Atmosphere, *p.* 313, *n.* 4003, and fol.
 — Diminution of it, on what it depends, *p.* 96, *n.* 2604, and fol.
 — greatest Degree of it that a Fluid can acquire, upon what it depends, *p.* 86, *n.* 2536.
Heat is communicated by a hot Body to one less hot, *p.* 82, *n.* 2504.
 — dilates Bodies, *p.* 64, *n.* 2403, *p.* 65, *n.* 2426, and fol.
Hot Bodies, many shine, if their Heat be encreased, II, *p.* 65, *n.* 2420.
Heavens, II, *p.* 286, *n.* 3766, and fol.
 — blue Colour of, whence, *p.* 286, *n.* 3768.
Heavenly Bodies, why they appear to be applied to the imaginary Sphere of the Heavens, II, *p.* 286, *n.* 3771, and fol.
Heavy Bodies don't always tends towards the Center of the Earth, II, *p.* 366, *n.* 4325.
Height from which a Body falling acquires a Velocity, with which, if it be moved in a Fluid, the Resistance from the second Cause, will be equal to the Weight of it, how discovered, I, *p.* 448, *n.* 1490, and fol.
 — of the Pole, II, *p.* 307, *n.* 3947.
 — is equal to the Latitude, *p.* 307, *n.* 3947.
 — by what Line determined, *p.* 366, *n.* 4326.
 — of the Stars, *p.* 305, *n.* 3921.
Height to which a Body must be raised, that it may raise greater Weights, by striking against the Scale of a Balance, I, *p.* 248, *n.* 1073, and fol.
Heliostate, by which the Sun's Rays are fixt, II, *p.* 107, *n.* 2660, and fol.
Hero's Fountain. See *Fountain*.
Heterogeneous Body. See *Body*.
Holes through which Water spouts, what Sort they ought to be, I, *p.* 381, *n.* 1596, and fol. *p.* 382, *n.* 1606, and fol.
Homogeneous Body. See *Body*.
Hook demonstrated that the Density of Copper was encreased by the Mixture of Fire, I, *p.* 375, *n.* 1573.
Horizon, II, *p.* 303, *n.* 3907.
 — oblique, *p.* 307, *n.* 3946.
 — parallel, *p.* 307, *n.* 3945.
 — right, *p.* 308, *n.* 3960.
 — *Hugens* determined the Aperture and Eye-glass of a Telescope, II, *p.* 198, *n.* 3228, *p.* 231, *n.* 3423.
Humor aqueous, II, *p.* 174, *n.* 3067.
 — crystalline, *p.* 174, *n.* 3065.
 — vitreous, *p.* 174, *n.* 3067.
Humor crystalline, Position and Figure of it changes, *p.* 177, *n.* 3094, and fol.
Hydraulic Machine, when it produces the greatest Effect, I, *p.* 429, *n.* 1858, and fol.
Hydraulic Machines that drive out Water by Fits are imperfect, *p.* 427, *n.* 1836, and fol.
 — some worked by Air, *p.* 428, *n.* 1844, and fol.
 — some by Animals and Men, *p.* 429, *n.* 1853, and fol.
 — some by Water *p.* 428, *n.* 1847, and fol.
 — some by Fire, *p.* 427, *n.* 1843.
Hydraulic Machines for raising Water, their Scope, *p.* 423, *n.* 1811.
Hydraulic Machines what Actions applied to them, *p.* 427, *n.* 1842.
Hydrostatical Comparison of Solids. See *Solids*.
 I.
Impenetrability See *Solidity*.
Impetus of a Fluid. See *Fluid*.
Impression, what required to change Motion, the Direction remaining, I, *p.* 271, *n.* 1147.
Inch cylindrick of Water, the Weight of it, I, *p.* 449, *n.* 1944.
Incidence, Angle of. See *Angle*.
Inconveniences happening in the Examination of the Sun's Rays, II, *p.* 107, *n.* 2654.
Index of the Axis in Peritrochio, I, *p.* 112, *n.* 499, *p.* 117, *n.* 526, and fol.
 — of a Machine, *p.* 112, *n.* 499.
 — of the Pulley, *p.* 112, *n.* 502, *p.* 118, *n.* 529, and fol.
 — of the Lever, *p.* 117, *n.* 522, and fol.
Indices of Machines, how discovered, *p.* 116, *n.* 521, and fol.
Inertia of a Body, I, *p.* 4, *n.* 19.
 — and Force differ relatively, *p.* 166, *n.* 691.
Inertia, Body resists by its. See *Body*.
Infinite, I, *p.* 8, *n.* 45.
Infinite is contained in a Finite, I, *p.* 8, *n.* 45.
 — we have no Idea of one, *p.* 9, *n.* 46.
Infinities, all are not equal, *p.* 11, *n.* 53.
 — Classes of them, *p.* 11, *n.* 54, and fol.
 — distant from one another by an infinite Series of intermediate Classes, *p.* 13, *n.* 60, and fol.
Inflection of Light. See *Light*.
Inflections of elastick Bodies in what Times performed, I, *p.* 337, *n.* 1397, and fol.
Intensity of an Action required, that an Hydraulic Machine may produce its greatest Effect, I, *p.* 429, *n.* 1856, and fol. *p.* 429, *n.* 1875, and fol.
 — of a Power. See *Power*.
 — of Sound. See *Sound*.
Introcession of the external Plate of an elastick Body that is struck, of what Kind, I, *p.* 333, *n.* 1373.
 Introcession

I N D E X.

- Introcession* of Parts is the same, if the Velocity is the same, *p.* 221, *n.* 949, and fol.
- Introcessions* of Parts in elastick Spheres, of what Kind, *p.* 334, *n.* 1375, and fol.
- are equal in the Concourse of three soft Bodies, tho' the Actions are unequal, *p.* 286, *n.* 1190, and fol.
- Inundation*, how it happens I, *p.* 407, *n.* 7122.
- Island* how produced in a River, I, *p.* 406. *n.* 1719, and fol.
- Judgment* of Distances. See *Vision*.
- of Magnitude. See *Vision*.
- Ivory*, Ball of, the Spot it makes by falling on Marble, I, *p.* 265, *n.* 1132.
- Jupiter*, II, *p.* 282, *n.* 3731.
- appears always round, *p.* 294, *n.* 3820.
- gravitates towards Saturn, *p.* 321, *n.* 4062, *p.* 343, *n.* 4190.
- His Action upon Mars, *p.* 345, *n.* 4197, and fol.
- Effect of his Action upon the Sun, *p.* 343, *n.* 4192.
- Axis of him shorter than the Diameter, *p.* 365, *n.* 4313.
- Motion and Distance of his Satellites, *p.* 283, *n.* 3741.
- Distance and Periodical time of the fourth Satellite, *p.* 338, *n.* 4159.
- L.
- Lanis (de)* his Experiment concerning falling Bodies, I, *p.* 247, *n.* 1071.
- Lantern-magick*, II, *p.* 231, *n.* 3424, and fol.
- Description of it, *p.* 231, *n.* 3425, and fol.
- Perfection of it, *p.* 233, *n.* 3435, and fol.
- Use of it, *p.* 233, *n.* 3434, *p.* 2935. *n.* 3440, and fol.
- Latitude* of a heavenly Body, II, *p.* 289. *n.* 3789.
- of a Place, *p.* 306, *n.* 3937.
- of a Wave. See *Wave*.
- Circles of, *p.* 306, *n.* 3938.
- Laws* of Elasticity. See *Elasticity*.
- according to which a Pendulum moves, that vibrates in a Cycloid, I, *p.* 326. *n.* 1335.
- of Nature, *p.* 3, *n.* 9, and fol.
- what in themselves, *p.* 2, *n.* 6.
- and with Respect to us, *p.* 2, *n.* 7.
- whence they arise, *p.* 2, *n.* 8.
- how investigated, *ibid.*
- for explaining what relates to Motion, *p.* 78, *n.* 355, *p.* 78, *n.* 357, *p.* 80, *n.* 361, II, *p.* 319, *n.* 4047.
- Lengthening of a Fibre, how discovered, I, *p.* 320, *n.* 1307.
- follows the Proportion of the lengthening Force, *p.* 321, *n.* 1308, and fol.
- of a Plate is in the Ratio of the Force that lengthens it, *p.* 324, *n.* 1323, and fol.
- Lengthenings* in Chords of different Length, from the adding of equal Weights, of what Kind, *p.* 323, *n.* 1318.
- of Fibres of the same Kind, of what Sort, *p.* 323, *n.* 1319.
- Lenze*, well centered, II, *p.* 165, *n.* 3004.
- Object, *p.* 191, *n.* 3185.
- Eye, *ibid.*
- of Glafs, *p.* 164, *n.* 3000.
- Axis of it. See *Axis*.
- if the Eye or Object be applied to it, the Picture is the same, *p.* 186, *n.* 3147, and fol.
- Affections of concave ones, *p.* 165, *n.* 3008, *p.* 166, *n.* 3019, and fol.
- Affections of convex ones, *p.* 165, *n.* 3007, and fol.
- Affections of polyhedrous ones, *p.* 187, *n.* 3156.
- Lever*, I, *p.* 45, *n.* 232, and fol.
- for raising Weights, *p.* 47, *n.* 240.
- compound, *p.* 61, *n.* 293.
- oblique, *p.* 46, *n.* 238, and fol.
- of the first Kind, *p.* 45, *n.* 234,
- of the second Kind, *ibid.*
- of the third Kind, *p.* 45, *n.* 234.
- Index of it. See *Index*.
- most perfect Use of it, *p.* 61, *n.* 495, and fol.
- the whole Actions of different Kinds of Levers, how compared, *p.* 114, *n.* 510.
- Ligaments* ciliary, II, *p.* 174, *n.* 3066.
- Light* and *Heat*, whether ever separated uncertain, II, *p.* 65, *n.* 2416, and fol.
- to be attributed to the same Cause, *p.* 63, *n.* 2395.
- differently affected by the Particles of different Bodies, *p.* 137, *n.* 2833.
- emitted from Bodies in right Lines, *p.* 65, *n.* 2411, *ibid.* *n.* 2414.
- why intercepted by Bodies, *p.* 237. *n.* 3447, and fol. *p.* 239, *n.* 3460.
- reflected where it can pass freely, *p.* 201, *n.* 3246, and fol.
- may be refracted, though the Mediums don't differ in Density, *p.* 138, *n.* 2842, and fol.
- sometimes not refracted, though the Mediums differ in Density, *p.* 138, *n.* 2844. and fol.
- often refracted towards the perpendicular, when it enters a rarer Medium, *p.* 138, *n.* 2847, and fol.

Light,

I N D E X.

- Light* with respect to Bodies, what, *p.* 65, *n.* 2421.
- and with respect to us, what, *p.* 65, *n.* 2412.
- of the Sun reflected by the Moon, how much it is weakened, *p.* 66, *n.* 2424.
- of the Sun, in what Time it comes to us from the Sun, *p.* 103, *n.* 2638, *p.* 106, *n.* 2655.
- passing through a Hole keeps its Direction, *p.* 98, *n.* 2610.
- passing through various Mediums terminated by parallel Plans, what Directions it hath, *p.* 140, *n.* 2855.
- passes through several opaque Bodies, *p.* 236, *n.* 3445, and fol.
- the Motion of it is equable, whilst it comes to the Atmosphere, *p.* 106, *n.* 2656.
- the Motion of it through a more refracting Medium, *p.* 164, *n.* 2998, and fol.
- the Acceleration of its Motion from Attraction, *p.* 133, *n.* 2818, and fol.
- Propagation of it not made by Pressure, *p.* 98, *n.* 2618, and fol.
- Propagation of it is instantaneous, *p.* 99, *n.* 2620, and fol.
- Ray of, *p.* 98, *n.* 2611.
- sometimes recedes from the perpendicular, *p.* 129, *n.* 2788, *p.* 130, *n.* 2799.
- moves in the same Lines, from what Part soever it proceeds, *p.* 129, *n.* 2789, *p.* 130, *n.* 2799.
- falling perpendicularly upon a Medium, is not turned out of its right way, *p.* 129, *n.* 2793, and fol.
- Direction of a Ray passing through a Medium, sometimes is not altered, *p.* 129, *n.* 2792, *p.* 130, *n.* 2799.
- Rays are attracted by Bodies, *p.* 116, *n.* 2722, *p.* 118, *n.* 2734, and fol. *p.* 127, *n.* 2780.
- Rays are repelled by Bodies, *p.* 116, *n.* 2726, *p.* 119, *n.* 2740, and fol.
- Inflection of the Rays, whence arising, *p.* 116, *n.* 2723, and fol.
- Reflection of the Rays of Light. See *Reflection*.
- their Refraction. See *Refraction*.
- the Velocity of Light determined from Observations made on Jupiter's Satellites, *p.* 99, *n.* 2622, and fol.
- and from Observations made on the fixed Stars, *p.* 103, *n.* 2639, and fol.
- Velocities of, in Air and Water, *p.* 132, *n.* 2811, *p.* 142, *n.* 2863.
- the Velocities of, in two given Mediums, bear a constant Ratio to one another, *p.* 131, *n.* 2808.
- the Way of it through the Air, how it becomes sensible, *p.* 131, *n.* 2801.
- Lightning*, Cause of, II, *p.* 89, *n.* 2566.
- Line* of swiftest Descent, I, *p.* 97, *n.* 453, *p.* 109, *n.* 487, *p.* 109, *n.* 489.
- how determined, *p.* 107, *n.* 483, and fol.
- Line* of Cavity, *p.* 208, *n.* 871.
- of Figure, *ibid.* *n.* 870.
- of Time, *p.* 209, *n.* 875.
- of Velocity, *p.* 208, *n.* 874.
- Lines* Caustick. See *Caustick*.
- Liquid* coloured sometimes appears of a different Colour, II, *p.* 276, *n.* 3681.
- Loadstone* attracts Iron, and is equally attracted by it, I, *p.* 81, *n.* 366.
- Logarithmick* Line, Formation of it, I, *p.* 460, *n.* 1992.
- Properties of it, *p.* 460, *n.* 1993.
- Logarithm* of the Ordinate, I, *p.* 460, *n.* 1994.
- of the Ratio, *ibid.* *n.* 1995.
- Longitude* of a heavenly Body, II, *p.* 289, *n.* 3788.
- of a Place, *p.* 307, *n.* 3941.
- Lucid* Body, its Surface, II, *p.* 98, *n.* 2613.
- Lucid* Bodies, *p.* 65, *n.* 2411.
- Lunation* II, *p.* 295, *n.* 3834.

M.

- Machine*, whereby the Ascent of Bodies is compared with their Descent, I, *p.* 86, *n.* 395.
- for comparing together the Dilatations of Air and the compressing Forces, II, *p.* 5, *n.* 2102, and fol.
- by which Experiments are made in compressed Air, *p.* 28, *n.* 2216, and fol.
- for making Experiments on the attraction and Repulsion of Light, *p.* 117, *n.* 2728, and fol.
- for making Experiments on oblique and compound Collision, *p.* 277, *n.* 1168.
- for comparing the Velocities of falling Bodies, I, *p.* 88, *n.* 402.
- of Use to demonstrate the Affections of the Wedge, *p.* 56, *n.* 279.
- another of this Kind examined, *p.* 60, *n.* 289.
- for comparing the Densities of solid Bodies, *p.* 372, *n.* 1559, and fol.
- for comparing the Descent in a Cycloid with the Descent in a right Line, *p.* 97, *n.* 454.
- A *Machine* whereby a Spring bent betwixt suspended Bodies is let loose, *p.* 255, *n.* 1090, and fol.
- for exploring the Laws of Elasticity, *p.* 318, *n.* 1297, and fol.
- for comparing the Densities of Fluids, *p.* 368, *n.* 1546, and fol. *p.* 370, *n.* 1554, and fol. *Machine*,

I N D E X.

Machine, for demonstrating the Experiments, concerning the lateral Pressure of Fluids in Motion, *p.* 419, *n.* 1787, and fol.

— for making Experiments on spouting Fluids, *p.* 378, *n.* 1584.

— for making Experiments upon Fluids spouting obliquely, *p.* 384, *n.* 1614.

— for making Experiments upon the Resistances of Fluids, *p.* 438, *n.* 1897, and fol.

— for demonstrating the lateral Pressure of Fluids, *p.* 349, *n.* 1446.

— for turning swiftly about Glass Globes, *p.* 73, *n.* 2459, and fol.

— for trying Money, *p.* 373, *n.* 1567, and fol.

— in which a Pendulum is moved by a Spring, *p.* 172, *n.* 732, and fol.

— for making Experiments on the Retardation of Pendulums, *p.* 458, *n.* 1990.

— for exhibiting the Affections of the inclined Plane, *p.* 74, *n.* 342, and fol.

— pneumatick, *p.* 14, *n.* 2139, and fol.

— simple, II, *p.* 17, *n.* 2158, and fol.

— in which a Weight is sustained by oblique Powers, I, *p.* 72, *n.* 335.

— for making Experiments on the Pressure of Fluids, *p.* 345, *n.* 1433, and fol.

— for projecting of Bodies, *p.* 123, *n.* 543.

— in which a Point is drawn different Ways by Threads, *p.* 70, *n.* 330.

— for fixing the Sun's Rays. See *Helioſtate*.

— simple, *p.* 51, *n.* 253; *p.* 52, *n.* 258, *p.* 55, *n.* 272, *p.* 58, *n.* 281, and fol.

— A *Machine* for making Experiments on Sound, II, *p.* 49, *n.* 2320, and fol.

— for demonstrating the Experiments concerning the Lever, by which Weights are moved, I, *p.* 47, *n.* 243.

— for demonstrating the Experiments concerning central Forces *p.* 129, *n.* 567, and fol.

— to be added to this last, to compare central Forces together, *p.* 137, *n.* 594, and fol.

— for comparing the Forces of Bodies falling directly, *p.* 197, *n.* 833.

— for making Experiments on innate Forces, and the Collision of Bodies, *p.* 179, *n.* 760, and fol.

— for making Experiments on oblique Forces, *p.* 49, *n.* 250, and fol.

— for letting down two Bodies in Vacuo at the same Time, II, *p.* 34, *n.* 2241, and fol.

— for turning Bodies about swiftly in Vacuo, *p.* 77, *n.* 2476, and fol, *p.* 78, *n.* 2483, and fol.

— Index of a Machine. See *Index*.

Machine most perfect Use of, *p.* 110, *n.* 493.

Machines compound, *p.* 60, *n.* 290, *p.* 61, *n.* 293, *p.* 61, *n.* 294, and fol. *p.* 63, *n.* 300, and fol.

— simple, *p.* 45, *n.* 202.

— Hydraulic. See *Hydraulic*.

— of Use in many Experiments, *p.* 33, *n.* 158, and fol.

— for demonstrating Experiments concerning the Refraction of Light, II, *p.* 122, *n.* 2755, and fol.

— by which the Velocities communicated by Springs let loose, are examined, I, *p.* 328, *n.* 1346, and fol. *p.* 329, *n.* 1354, and fol.

— Intention of Hydraulic. See *Hydraulic*.

— Indices. See *Indices*.

— Use of, *p.* 110, *n.* 490, and fol.

Magnitude apparent of an Object, upon what it depends, II, *p.* 181, *n.* 3117.

— is increased by the Interposition of a plane Mirror, *p.* 183, *n.* 3128.

— seen through a Glass is altered, *p.* 184, *n.* 3133, *p.* 185, *n.* 3143, *p.* 186, *n.* 3148, *p.* 187, *n.* 3157, and fol.

— in the *Newtonian* catoptrick Telescope, *p.* 220, *n.* 3354.

— in the *Gregorian*, *p.* 222, *n.* 3373, and fol. *p.* 228, *n.* 3406, and fol.

Mairan, (*de*) measured the Length of a Pendulum, that performed its Vibrations at *Paris*, in a Second, II, *p.* 366, *n.* 4334, *p.* 393, *n.* 4416.

Maraldi opposes the Opinion of *Romer*, II, *p.* 101, *n.* 2633.

Mariotte determined the Velocity of Wind, II, *p.* 53, *n.* 2342.

— made an Experiment upon Water running out of a given Hole, I, *p.* 398, *n.* 1664.

— mentions an Experiment concerning the Dilatation of an elastick Fluid, II, *p.* 12, *n.* 2133.

— not cautious enough in his Experiment concerning the Colours of Rays, *p.* 251, *n.* 3532.

— demonstrates a mechanical Paradox, I, *p.* 76, *n.* 351.

Mars, II, *p.* 282, *n.* 3730.

— sometimes appears gibbous, *p.* 294, *n.* 3821.

Mass, what, I, *p.* 177, *n.* 748.

Masses of Bodies, about the common Center of Gravity, if they be multiplied by the Velocities, the Sum of the Products on both Sides is sometimes equal, *p.* 299, *n.* 1226, and fol.

Matter

I N D E X

- Matter of the Heavens very subtile*, II, p. 333, n. 4134.
- does not move the heavenly Bodies, p. 332, n. 4131, and fol.
- remaining in a Receiver exhausted of the Air, though 'tis dilated, yet keeps its Elasticity, p. 24, n. 2192, and fol.
- the Quantiy of, equal to a Grain of Sand, may be diffused through any Space, I, p. 7, n. 37.
- Divisibility of. See *Divisibility*.
- Maupertuis, (de)* has described the Measures made of the Earth's Figure, II, p. 393, n. 4415.
- Measure of Forces from their Generation*, I, p. 170, n. 721, and fol.
- Medium*, II, p. 127, n. 2776.
- Meniscus*, II, p. 164, n. 3001.
- Mercury contains Fire*, II, p. 79, n. 2489.
- joins itself to Gold and Tin, I, p. 19, n. 86.
- shines in Vacuo, II, p. 80, n. 2491, and fol.
- repells Iron, I, p. 20, n. 87, and fol.
- Mercury is repelled by Glafs*, I, p. 20, n. 90.
- how cleansed, II, p. 81, n. 2495.
- Pillar of it sustained by the Air, p. 2, n. 2085.
- Density of it, I, p. 373, n. 1563.
- Mercury the Planet*, II, p. 281, n. 3727.
- Meridian Line*, II, p. 304, n. 3914, p. 306, n. 3936.
- Meridian of a Place*, II, p. 306, n. 3934.
- first, p. 306, n. 3940.
- Meridians*, p. 300, n. 3881.
- Mersennus* has given an Experiment concerning falling Bodies, I, p. 247, n. 1071.
- Metals*, if two are mixed, to determine how much of both the Mixture contains, I, p. 374, n. 1570, and fol.
- Metears fiery, the Cause of them*, II, p. 89, n. 2566.
- Microscope*, II, p. 189, n. 3173.
- magnifies small Objects, p. 189, n. 3174, and 3176.
- compound magnifies more, p. 190, n. 3180, and fol.
- Aperture of it, p. 191, n. 3186.
- Field of it, p. 190, n. 3175.
- upon what it depends, p. 192, n. 3188.
- Minutes*, II, p. 310, n. 3970.
- Mirrors burning*, II, p. 210, n. 3300, p. 211, n. 3304, and fol.
- conical, convex, p. 216, n. 3336.
- cylindrical, convex and concave, *ibid.*
- plane, p. 205, n. 3263, and fol.
- spherical, concave, p. 206, n. 3269.
- how they disperse the Rays, p. 225, n. 3374, and fol.
- where and what Sort of an Appearance of Objects they exhibit, p. 215, n. 3325, and fol.
- never represent Objects exactly, p. 216, n. 3334.
- how they reflect parallel, direct, and neighbouring Rays, p. 209, n. 3296, and fol.
- how they reflect oblique Rays, p. 211, n. 3307, and fol.
- spherical, convex, p. 206, n. 3269, and fol.
- according to what Laws they reflect Rays, p. 206, n. 3270, and fol.
- Objects seen in them, where and how they appear, p. 206, n. 3275, and fol. p. 208, n. 3288, and fol.
- Burning Mirrors*, their Diameter determined, p. 210, n. 3301, p. 217, n. 3337, and fol.
- Phænomena of plane ones, p. 205, n. 3263, and fol.
- Molineux* endeavoured to determine the Motion of Light, p. 103, n. 2639.
- Moon*, II, p. 350, n. 4219, and fol.
- compared with the Earth, p. 284, n. 3751.
- with what Force removed out of the Plane of its Orbit, p. 360, n. 4278, and fol.
- is retained in its Orbit, p. 323, n. 4076.
- the Way it runs through in a Minute, p. 323, n. 4077.
- Why it always turns the same Face towards the Earth, p. 302, n. 3899, and fol, p. 388, n. 4518.
- appears greater near the Horizon, p. 81, n. 3119.
- by what Forces disturbed, p. 351, n. 4224, p. 352, n. 4230, p. 361, n. 4245, and fol, p. 363, n. 4302, and fol.
- disturbs the Motion of the Earth, p. 348, n. 4212.
- Appearances of, p. 295, n. 3831, and fol.
- Axis of, inclined to the Plane of its Orbit, p. 303, n. 3904, p. 389, n. 4522,
- its Density determined, p. 386, n. 4503, and fol.
- Proportion of its Density to that of the Sun, p. 386, n. 4506.
- and to that of the Earth, p. 387, n. 4508.
- its Distance, p. 338, n. 4161, p. 340, n. 4173, p. 364, n. 4305.
- its Distance not always the same, p. 356, n. 4254.
- its periodical Time, if it be moved about the Earth at rest, p. 338, n. 4156, and fol. p. 340, n. 4177, and fol.
- Moon,*

I N D E X.

- Moon*, Eclipse of, *p.* 296, *n.* 3844.
 — when an Eclipse happens, *p.* 296, *n.* 3846, and fol.
 — central Eclipse, *p.* 297, *n.* 3853.
 — partial, *ibid.*, *n.* 3851.
 — total, *ibid.*, 3852.
 — Figure of, determined, *p.* 387, *n.* 4511, and fol.
 — Gravity of towards the Earth altered by the Action of the Sun, *p.* 323, *n.* 4077, *p.* 339, *n.* 4162.
 — its Gravity not always the same, *p.* 350, *n.* 4219, and fol. *p.* 364, *n.* 4304.
 — when there will be an *Æquilibrium* between the Parts of the Moon, *p.* 388, *n.* 4518.
 — Motion of, *p.* 369, *n.* 3740, and fol.
 — Motion of the Apfides, *p.* 358, *n.* 4263, and fol.
 — about its Axis is equable, *p.* 389, *n.* 4521.
 — in what Time this Motion is performed, *p.* 388, *n.* 4519.
 — libratory Motion of, *p.* 303, *n.* 3902, and fol.
 — Motion of the Nodes, *p.* 361, *n.* 4289, and fol.
 — Effect of its Motion about its Axis, *p.* 302, *n.* 3899, and fol. *p.* 388, *n.* 4518.
 — physical Explanation of this Motion, *p.* 348, *n.* 4210, and fol.
 — Convexity of its Orbit not always the same, *p.* 389, *n.* 4252, and fol.
 — Change of the Inclination of its Orbit, *p.* 362, *n.* 4293, and fol.
 — periodical Time of, *p.* 364, *n.* 4305.
Morning. See *Twilight*.
Motion, I, *p.* 26, *n.* 111.
 — absolute of several Bodies, is not changed in Collision, *p.* 303, *n.* 1241.
 — accelerated, *p.* 377, *n.* 368, and 372, and fol.
 — is accelerated equably, *p.* 82, *n.* 370.
 — of a falling Body is accelerated, *ibid.*
 — apparent, II, *p.* 285, *n.* 3765, *p.* 287, *n.* 3775, and fol.
 — absolute, differs from Relative, *p.* 285, *n.* 3765. *p.* 288, *n.* 3778.
 — of the Center of Gravity. See *Center of Gravity*.
 — is communicated successively, I, *p.* 169, *n.* 710.
 — may be communicated with any Force lost, *p.* 232, *n.* 1003, and fol.
 — compound, *p.* 79, *n.* 360.
 — is examined, *p.* 271, *n.* 1147, and fol.
 — of a Body may be resolved into two others several Ways, *p.* 273, *n.* 1155.
 — of a Body descending upon a Plane, *p.* 84, *n.* 382, and fol.
 — of Bodies revolving round a common Center of Gravity, *p.* 347, *n.* 4208, and fol.
 — of non-elastick Bodies after oblique Percussion, *p.* 280, *n.* 1174, and fol.
 — of Bodies striking against one another obliquely, how described, *p.* 276, *n.* 1164, and fol. *p.* 278, *n.* 1169, and fol.
 — diurnal, *p.* 300, *n.* 3878.
 — the diurnal Motion not observed in the Poles of the World, *p.* 301, *n.* 3885.
 — it ought to be referred to the Rotation of the Earth above its Axis, *p.* 336, *n.* 4148.
 — double of it, I, *p.* 26, *n.* 115.
 — in antecedentia, or retrograde, *p.* 280, *n.* 3716.
 — in consequentia, or direct, *ibid.* *n.* 3715.
Motion in a Circle, I, *p.* 152, *n.* 649, and fol.
 — in a Curve, how made, *p.* 128, *n.* 559, and fol.
 — in a Cycloid, *p.* 102, *n.* 467, and fol.
 — in an Ellipse, *p.* 154, *n.* 656, and fol.
 — in an agitated Ellipse, *p.* 160, *n.* 668, and fol.
 — in an agitated Orbit, *p.* 157, *n.* 660, and fol.
 — of a Pendulum. See *Pendulum*.
 — from Projection, made up of two Motions, *p.* 122, *n.* 541.
 — and rest, differ relatively, *p.* 167, *n.* 695.
 — retarded, *p.* 82, *n.* 369.
 — tremulous in Machines, how to be avoided, *p.* 233, *n.* 1007, and fol.
 — of a Wave. See *Wave*.
Motion absolute compared, with the Motion of single Bodies, *p.* 301, *n.* 1235, and fol. *p.* 304, *n.* 1249, and fol.
 — Continuation of, *p.* 78, *n.* 355.
 — Direction of, *p.* 27, *n.* 122.
 — Laws of, *p.* 78, *n.* 355, and fol. II, *p.* 319, *n.* 4047.
 — Change of, *p.* 78, *n.* 357.
Motions two don't disturb one another, I, *p.* 78, *n.* 358.
 — of three Bodies after the Stroke in triple Collision, *p.* 309, *n.* 1260, and fol.
Mouths of Rivers. See *Rivers*.
Moveable Body is, I, *p.* 4, *n.* 17.
Multiplication mechanical, I, *p.* 44, *n.* 229.
Musical Tone. See *Tone*.
 N.
Nadir, II, *p.* 304, *n.* 3913.
 G g g
Nerve

I N D E X.

Nerve Optic, II, 174, n. 3068.

Newton's Telescopes. See *Telescopes Catoptric*.

New Moon, II, p. 296, n. 3838.

Nodes of the Planets, II, p. 280, n. 3709.

— Line of them, p. 280, n. 3710.

Number of the Center about which a Line is moved, I, p. 241, n. 1044.

O.

Objects how painted on a white Plane, II, p. 172, n. 3058, and fol.

Oblique Rays. See *Rays*.

Obstacle is moved by Pressure, I, p. 28, n. 127, p. 167, n. 698.

— and that according to certain Laws, p. 29, n. 131, and fol.

Odorous Parts the great Subtily of them, I, p. 8, n. 43.

Oil, Density of to that of Borax, II, p. 138, n. 2846.

— Drop of, ascends between Glass Plates, I, p. 19, n. 85. p. 25, n. 110.

Oily Parts in Bodies, II, p. 87, n. 2550.

Opacity depends upon the Pores, II, p. 237, n. 3449.

— arises from a Reflection and Deflection of Light, p. 237, n. 3447, and fol.

Opaque Body, II, p. 98, n. 2615.

Opaque Bodies, how they become transparent, p. 237, n. 3449, and fol.

Opposition of Heavenly Bodies, II, p. 290, n. 3794.

Orbits of Planets. See *Planets*.

Orifices the greater in Hydraulic Machines to be preferred to the less, I, p. 426, n. 1829.

— in Hydraulic Machines, how determined in certain Cases, p. 426, n. 1830, and fol.

— Diameters of them in Hydraulic Machines, what Ratio they bear to the Height of the Water thrown out, p. 425, n. 1826, p. 432, n. 1871, and fol.

Oscillation, Center of. See *Center*.

P.

Parabola, I, p. 123, n. 542, p. 124, n. 545.

— Property of it, p. 2, n. 55.

Paradox Mechanical, I, p. 76, n. 352, and fol.

— demonstrated, p. 77, n. 354.

— Explanation of one that is deduced from the Property of Elastick Bodies, p. 270, n. 1146.

Parallax annual, II, p. 316, n. 4025.

— of the Moon only determined by Observations, p. 305, n. 3924.

— of the Stars, p. 305, n. 3923, and fol.

— Part immersed of a Body floating in a Fluid, I, p. 361, n. 1511, and fol.

— Parts immersed of Bodies floating in Fluids, their Proportion to one another, p. 362, n. 1515.

— of Bodies descending into a Fluid by various Weights, are to one another as the Weights, p. 362, n. 1516, and fol.

— of a solid, swimming in Fluids to be compared, are inverfly as the Densities of the Fluids, p. 370, n. 1553.

— what are separated in the Combustion of Bodies, II, p. 87, n. 2547, and fol.

Pellucid Body, II, p. 98, n. 2614.

Pellucid Bodies become opaque by separating their Parts, p. 238, n. 3454, and fol.

— all the small Parts of Bodies are pellucid, p. 236, n. 3443, and fol.

Pendulum, I, p. 89, n. 404.

— sometimes has no Center of Percussion, p. 243, n. 1054, and fol.

— descends faster in an Arc than in the Chord of it, p. 92, n. 417.

— how moved by a Spring, p. 172, n. 732, and fol.

— may be considered as a Lever, p. 252, n. 1078.

— how it may run through a Cycloid, p. 91, n. 410, p. 100, n. 460.

— compound, p. 93, n. 424.

— if it runs against a fixed Obstacle; it acts differently, p. 242, n. 1048, and fol. p. 242, n. 1052, and fol.

— Angle of, I, p. 95, n. 440.

— Force of a simple one, in what ratio, p. 187, n. 793.

— Force of a compound one how determined, p. 187, n. 794, and fol.

— Computations of the Motions of, p. 189, n. 801, and fol.

— Length of, p. 97, n. 451.

— what Sort of one required, to have its Revolutions in the same Time, in different Places of the Earth, II, p. 366, n. 4334, and fol.

— Motion of, I, p. 89, n. 404, and fol.

— Motion of, in a Fluid, p. 456, n. 1981, and fol.

— Velocity of, p. 95, n. 437.

— angular Velocity of, *ibid.* n. 438.

— in what Ratio it is, p. 96, n. 446, and fol.

— Velocity of any Point of it, *ibid.* n. 448.

— Velocities of, in unequal Vibrations, p. 95, n. 441.

— that are very small, *ibid.* n. 442, p. 96, n. 445. *Pendulum,*

I N D E X.

- Pendulum*, the small Vibrations are made in the same Time, *p.* 90, *n.* 407.
- Vibrations of in a Circle, compared with the Vibrations in the Chords, *p.* 90, *n.* 406, *p.* 92, *n.* 416.
- no Matter of what Weight, or of what Matter made, *p.* 92, *n.* 421.
- Squares of their Angles. *p.* 97, *n.* 450.
- Velocities of equal ones, when the Angles are equal, but Gravities different, *p.* 96, *n.* 444.
- Velocities of different ones, when the Angles are equal. *p.* 95, *n.* 443.
- Durations of their unequal Vibrations, *p.* 92, *n.* 418, and fol. *p.* 96, *n.* 449.
- Forces of, *p.* 187, *n.* 792, and fol.
- Use of in Clocks. *p.* 94, *n.* 429.
- Penumbra*, II, *p.* 298, *n.* 3863.
- Perceptions* answer to the Motions of the Nerves, and how, II, *p.* 48, *n.* 2310, *p.* 176, *n.* 3077, and fol.
- Percussion* oblique considered, I, *p.* 276, *n.* 1161, and fol.
- of equal and elastick Bodies, what Change they produce in Motion, *p.* 277, *n.* 1167.
- Centers of. See *Center*.
- Perihelion*, II, *p.* 279, *n.* 3702.
- Periodic* Time, I, *p.* 137, *n.* 592.
- Phænomena* natural, I, *p.* 1, *n.* 2.
- comprehend also the Motions in the human Body, *ibid.* *n.* 3.
- explained by Physicks, *p.* 2, *n.* 5.
- Phosphorus* of Urine, II, *p.* 81, *n.* 2498.
- shines in Vacuo, *p.* 95, *n.* 2597, and fol.
- Physicks* conversant about natural Things, I, *p.* 1.
- Picture* of Objects in the Eye is inverted, II, *p.* 175, *n.* 3070, and fol. *p.* 178, *n.* 3101.
- Picture* of Objects falls within the Eye, *p.* 175, *n.* 3073.
- Pillar*, used in the Experiments, I, *p.* 34, *n.* 162, and fol.
- Pipes* through which Water is brought, of what Sort they should be, I, *p.* 382, *n.* 1601, and fol.
- Placer*, II, *p.* 277, *n.* 3683.
- Place* what, I, *p.* 26, *n.* 112.
- apparent of a Body in the Sphere of the fixed Stars, II, *p.* 287, *n.* 3774.
- relative, I, *p.* 26, *n.* 114.
- true, *ibid.* *n.* 113.
- Planet*, Axis of, II, *p.* 280, *n.* 3718.
- the Axis of the Planets is carried with a parallel Motion, *ibid.* *n.* 3721.
- mean Distance of from the Sun, *p.* 279, *n.* 3700.
- Figure of, determined from Observations, *p.* 374, *n.* 4412.
- how varied from its Motion about its Axis, according to its different Constitution, *p.* 373, *n.* 4400, and fol.
- Poles of, *p.* 281, *n.* 3722.
- the Figure of a spherical one from the fluid Matter, changes by the Revolution about the Axis, *p.* 364, *n.* 4311, *p.* 338, *n.* 4375, and fol.
- Planets*, II, *p.* 278, *n.* 3692.
- are higher under the Æquator, than under the Poles, *p.* 364, *n.* 4311.
- describe elliptic Lines in their Motions, *p.* 278, *n.* 3696.
- that are immoveable, *p.* 342, *n.* 4184.
- gravitate towards the Sun, *p.* 320, *n.* 4054.
- revolve about their Axes, *p.* 28, *n.* 3319, *p.* 300, *n.* 3875.
- revolve about the common Center of Gravity of the whole System, *p.* 342, *n.* 4183.
- inferior, *p.* 282, *n.* 3735.
- superior, *ibid.* *n.* 3734.
- primary, *p.* 278, *n.* 3694.
- secondary, *p.* 278, *n.* 3695, *p.* 282, *n.* 3737, and fol.
- gravitate towards their Primaries, *p.* 320, *n.* 4055.
- and towards the Sun, *p.* 320, *n.* 4057.
- retrograde, *p.* 290, 3801.
- stationary, *ibid.* *n.* 382.
- Effects of their mutual Actions, *p.* 345, *n.* 4199.
- Densities of, *p.* 337, *n.* 4152, and fol. *p.* 339, *n.* 4168, and fol.
- Distance of, how discovered, *p.* 282, *n.* 3733.
- Figures of determined, *p.* 364, *n.* 4306, and fol. *p.* 388, *n.* 4375, and fol.
- Appearances of the inferior ones, *p.* 290, *n.* 3799, and fol.
- Phænomena depending upon their Opacity, *p.* 292, *n.* 3811, and fol.
- Appearances of the superior ones, *p.* 293, *n.* 3816, and fol.
- Motions of, *p.* 280, *n.* 3711, and fol.
- Situation of their Orbits why changed, *p.* 345, *n.* 4199, and 4202.
- Orbits of the primary how disposed, *p.* 278, *n.* 3697, *p.* 279, *n.* 3706.
- Appearances of the secondary, *p.* 294, *n.* 3822, and fol.
- and their Motions, *p.* 282, *n.* 3739, *p.* 346, *n.* 4205, and fol.
- G g g 2
- their

I N D E X.

- their Weights, *p.* 339, *n.* 4162, and fol.
- Squares of their periodic Times, *p.* 283, *n.* 3747
- Plane* in an Hydraulic Machine, with what Velocity it ought to be thrust out, to raise the greatest Quantity of Water, I, *p.* 431, *n.* 1865, and fol, *p.* 434, *n.* 1880, and fol.
- inclined, *p.* 73, *n.* 328.
- Descent of a Body upon it, *ibid.* *n.* 340, and fol. *p.* 74, *n.* 344. and fol.
- Descent of heavy Bodies upon it, *p.* 84, *n.* 381, and fol.
- Height of an inclined Plane, *p.* 73, *n.* 340.
- Length of, *ibid.* *n.* 339.
- Plate* is moved according to the Laws of a Pendulum vibrating in a Cycloid, I, *p.* 326, *n.* 1335.
- elastick, if one End being fixt, it be bent, it is lengthened unequally in different Points, *p.* 325, *n.* 1332, and fol.
- of Metal, how it becomes elastick, *p.* 368, *n.* 1282.
- may lose its Elasticity, *ibid.*
- then does not reflect Light, if its Thickness be too much diminished, II, *p.* 925, *n.* 3640, and fol.
- Plate Curve*, the Introcessions of it are as the Weights, that it is loaded with, I, *p.* 327, *n.* 1339.
- and the Inflections of it are proportional to the Forces with which it is retained in these Inflections, *p.* 326, *n.* 1336, and fol.
- Lengthening of. See *Lengthening*.
- Colour of a thin one, on what it depends, II. *p.* 269, *n.* 3634, and fol.
- the Colour is encreased with the Thickness, *p.* 269. *n.* 3631, *p.* 272, *n.* 3651.
- thin ones transmit some Rays, and reflect others, *p.* 267, *n.* 3620, and fol.
- Elasticity of. See *Elasticity*.
- Variation of the Colour of thin ones, arising from the different Situation of the Eye, *p.* 272, *n.* 2652, *n.* 352, *p.* 273, *n.* 3657.
- Point* highest of a Way run through by a projected Body, *p.* 126, *n.* 554, and fol.
- of Dispersion of Rays, II, *p.* 143, *n.* 2871.
- this Point is determined, *p.* 141, *n.* 2898.
- radiant, *p.* 143, *n.* 2869.
- or Point of Dispersion, when at a greater or less Distance, *p.* 143, *n.* 2873.
- drawn by three Powers, when it is at rest, I, *p.* 66, *n.* 315, and fol. *p.* 68, *n.* 320, and fol.
- drawn by four Powers, *p.* 69, *n.* 325, and fol.
- drawn by five Powers, *p.* 70, *n.* 328, and fol.
- Points* correspondent in good Eyes, II, *p.* 179, *n.* 3106.
- of Suspension. See *Balance*.
- Polar Circles*, II, *p.* 302, *n.* 3897, and fol.
- Pole* antarctick, *p.* 302, *n.* 3896.
- arctick, *ibid.*
- Altitude of. See *Altitude*.
- Poles* of the Ecliptick. See *Ecliptick*.
- of the World, *p.* 300, *n.* 3877.
- how far distant the Poles of the World are from those of the Ecliptick, *p.* 301, *n.* 3889.
- of a Planet. See *Planet*.
- Power*, what, I, *p.* 27, *n.* 123.
- applied to the Axis in Peritrochio, *p.* 51, *n.* 255, and fol.
- which is joined to a Pulley, *p.* 63, *n.* 303.
- which is joined to a Screw, *p.* 58, *n.* 283, *p.* 63, *n.* 304, and fol.
- which is joined to a Wedge, *p.* 55, *n.* 277, *p.* 57, *n.* 280, *p.* 59, *n.* 287, and fol.
- applied to compound Machines, *p.* 61, *n.* 291, and fol. *p.* 64, *n.* 306, and fol.
- applied to Sheaves joined, *p.* 63, *n.* 301, and fol.
- Power* applied to Wheels joined, *p.* 62, *n.* 298.
- to Pulleys, *p.* 52, *n.* 259, and fol.
- direct, *p.* 65, *n.* 308.
- oblique, *ibid.* *n.* 309, and fol.
- applied to Machines, *ibid.* *n.* 310, and fol.
- Resistance of, how it increases, *p.* 30, *n.* 141.
- Powers* drawing a Lever two Ways, *p.* 49, *n.* 248, and fol.
- sustaining a Weight obliquely, *p.* 71, *n.* 332, and fol. *p.* 72, *n.* 336, and fol.
- several may destroy themselves, *p.* 31, *n.* 146.
- what Sort of proper to raise Weights, *p.* 48, *n.* 246.
- Actions of, how they differ from one another, *p.* 28, *n.* 129, *p.* 30, *n.* 142.
- their Intensities, in what Ratio, *p.* 29, *n.* 131, and fol.
- Power* of a Quantity how raised to a greater, I, *p.* 162, *n.* 675, and fol.
- Pound*, (*℥*.) defends the Opinion of *Romer*, II, *p.* 102, *n.* 2636.
- Procession* of the *Æquinoxes*. See *Æquinoxes*.
- Pressure*

I N D E X.

- Pressure* equal every Way may be sustained by soft and brittle Bodies, without any Alteration of their Figure, I, p. 353, n. 1471, and fol.
- is often destroyed in Part by a contrary Pressure, p. 167, n. 698.
- differs from Force, p. 169, n. 714, and fol.
- communicates Velocity to a Fluid, p. 376, n. 1575, and fol.
- of a Fluid equal every Way, does not alter the Figure of any Drop, p. 354, n. 1473, and fol.
- Power* upon a solid immersed encreases in the Ratio of the Height of the Fluid above the Solid, p. 353, n. 1468, and fol.
- on it, every Way is nearly equal, p. 353, n. 1470.
- upon the lower Parts of a Fluid, exerts its Action every Way, and that equally, p. 341, n. 1418, and fol.
- Pressure* what exerted upon the Surface by a Fluid, p. 344, n. 1431, p. 347, n. 1441, and fol. p. 350, n. 1453.
- lateral of a Fluid is equal to the Vertical, p. 351, n. 1445, p. 349, n. 1447, p. 351, n. 1457.
- of a Fluid upwards, equal to the Pressure downwards, p. 349, n. 1448, and fol. p. 351, n. 1454.
- generates Force, p. 167, n. 695, and fol.
- badly compared with innate Force, p. 168, n. 704.
- overcome by Force, *ibid.* n. 701, and fol.
- or Power. See *Power*.
- Action of. See *Action*.
- Direction of that of a Fluid is perpendicular to the Surface pressed, p. 355, n. 1474.
- by it the Parts of Bodies cohere together, p. 217, n. 926.
- by it alone a Body in Motion, can communicate Motion to another Body, p. 232, n. 1003, and fol.
- equal, p. 28, n. 124.
- equal ones destroy one another, *ibid.* n. 125, p. 30, n. 139, p. 30, n. 143, and 145.
- Ratio of Pressures to one another, p. 28, n. 126.
- Prisms* with Stands, II, p. 254, n. 3552, and fol.
- Problems* relating to Bodies projected in a Fluid, I, p. 468, n. 2042, and fol.
- Progression* may be continued in infinitum, I, p. 8, n. 45, and fol.
- Projection* of a Body to a given Distance, I, p. 125, n. 547, and fol.
- Projection* of a Body to a given Distance, through a given Point, p. 127, n. 557, and fol.
- of heavy Bodies, p. 122, n. 540, and fol.
- Body projected upwards, has a two-fold Motion, II, p. 336, n. 4150.
- Proportion* Rule of, performed mechanically, I, p. 44, n. 231.
- Pupil*, II, p. 173, n. 3064.
- Q.
- Qualities* of all Bodies, I, p. 3, n. 11.
- Quantity* of a Fluid running out of Vessels. See *Fluid*.
- R.
- Radiant*. See *Point*.
- Rain*, why it falls, II, p. 86, n. 2543.
- Rainbow*, when it happens, II, p. 262, n. 3591, and fol.
- what Motion of Light required to form it, p. 259, n. 3577, and fol. p. 264, n. 3601, and fol.
- two often observed, p. 263, n. 3599, and fol.
- Ray* of Light, II, p. 98, n. 2611.
- incident, p. 128, n. 2784.
- falling upon a spherical Surface, separating the Mediums, how refracted, p. 151, n. 2919, and fol.
- reflected, p. 200, n. 3238.
- refracted, p. 128, n. 2785.
- every Proceeding from the Sun, is heterogeneous, p. 240, n. 3470.
- passing through the Center of a spherical Surface, is not turned out of its Way, p. 151, n. 2916.
- Rays* converging and more converging, p. 143, n. 2874.
- when they become more converging, p. 146, n. 2891, and 2894.
- when they become less converging, p. 146, n. 2888.
- falling upon a spherical Surface, sometimes are not refracted, p. 154, n. 2942, p. 157, n. 2970.
- become parallel, p. 156, n. 2951, p. 157, n. 2971.
- less or more converging, p. 155, n. 2943, and fol. p. 156, n. 2961.
- direct, p. 144, n. 2878.
- and dispersed a little, how refracted, if they fall upon a spherical Surface, p. 152, n. 2929, and fol. p. 161, n. 2989.
- parallel how refracted, if they fall

I N D E X.

- on a spherical Surface, *p.* 152, *n.* 2927.
- diverging, *p.* 143, 2868.
- more diverging, *p.* 143, *n.* 2872.
- Rays diverging that fall upon a spherical Surface, sometimes become converging, *p.* 154, *n.* 2936, and fol.
- those are not bent by Refraction, *p.* 155, *n.* 2947.
- but go out parallel, *p.* 154, *n.* 2938, and fol.
- are dispersed more, *p.* 155, *n.* 2948, and fol. *p.* 156, *n.* 2960, *p.* 157, *n.* 2968, *p.* 158, *n.* 2973.
- less diverging, *p.* 154, *n.* 2940, and fol. *p.* 155, *n.* 2948, *p.* 156, *n.* 2959.
- efficacious, *p.* 260, *n.* 3581, *p.* 264, *n.* 3601, and fol.
- Heterogeneous, *p.* 240, *n.* 3468.
- Homogeneous, *p.* 239, *n.* 3467.
- entering the Eye, converge, *p.* 174, *n.* 3069.
- are not altered by Permixture, *p.* 355, *n.* 3559, and fol.
- nor by Reflection, *p.* 251, *n.* 3537, and fol.
- nor by Refraction, *p.* 248, *n.* 3514, and fol.
- oblique, *p.* 144, *n.* 2873.
- parallel falling upon Water surrounded with Air, *p.* 259, *n.* 3577, and fol.
- falling upon a spherical Surface, sometimes become converging, *p.* 153, *n.* 2934, and fol. *p.* 156, *n.* 2956.
- and diverging, *p.* 155, *n.* 2945, and fol. *p.* 157, *n.* 2967, and 2972.
- passing out of one Medium into another, when they are parallel after Refraction, *p.* 144, *n.* 2879, and fol.
- passing through Crystal, how refracted, *p.* 248, *n.* 3518, and fol.
- all don't always undergo the same Refraction, *p.* 239, *n.* 3465, *p.* 240, *n.* 3472, and fol.
- Rays of the Sun fixed by an Helioſtate, *p.* 107, *n.* 2660, and fol. *p.* 113, *n.* 2709, and fol.
- passing through the Center of a Lense, *p.* 168, *n.* 3038, and fol.
- passing through a concave Lense, their Direction, *p.* 166, *n.* 3020, and fol.
- passing through a convex Lense, their Direction, *p.* 165, *n.* 3010, and fol.
- Direction of, not altered in plane Glasses, *p.* 165, *n.* 3005.
- of direct ones, sometimes there is no Point of Dispersion, or Focus, *p.* 147, *n.* 2895.
- Refraction of oblique ones, falling on a plane Surface, is examined, *p.* 147, *n.* 2897, *p.* 149, *n.* 2906.
- Refraction of, a little dispersed, falling on a spherical Surface, *p.* 159, *n.* 2979, and fol. *p.* 161, *n.* 2990.
- Refraction of converging or diverging ones, *p.* 159, *n.* 2981, and fol. *p.* 162, *n.* 2994, and fol.
- no Point of Dispersion or Focus of these, *p.* 148, *n.* 2901, and fol. *p.* 160, *n.* 2987.
- of Parallel passing through a Lense, the Point of Concourse or Dispersion, *p.* 167, *n.* 3029, and fol. *p.* 171, *n.* 3054.
- Refrangibility of those reflected by Bodies, on what it depends, *p.* 273, *n.* 3659, and fol.
- *what remains relating to the Rays of Light, see in Light.*
- Reaction is contrary to Action, I, *p.* 80, *n.* 361, and fol.
- of the Particles of Fluids is one Cause of the Resistance, which a Body, moved in it, undergoes, *p.* 437, *n.* 1891, and fol.
- Rectangle of Use in Experiments relating to Light, II, *p.* 126, *n.* 2775.
- Reflection of Light from Bodies, II, *p.* 172, *n.* 3057, *p.* 197, *n.* 3225.
- from a polished Surface, *p.* 200, *n.* 3236, *p.* 205, *n.* 3262.
- with what Force made, *p.* 203, *n.* 3256.
- has a Relation to the refracting Force, *p.* 55, *n.* 2359, and fol.
- Reflection of Light is not given in the Surface of Bodies, *p.* 204, *n.* 3261.
- does not arise from the striking of Light against the solid Parts of Bodies, *p.* 201, *n.* 3246, and fol.
- Angle of Reflection, I, *p.* 276, *n.* 1162, II, *p.* 200, *n.* 3239.
- is equal to the Angle of Incidence, I, *p.* 276, *n.* 1163, II, *p.* 200, *n.* 3241, and fol.
- Laws of it, *p.* 201, *n.* 3244, and fol.
- Refraction of Light, II, *p.* 287, *n.* 2777.
- when it happens, *p.* 288, *n.* 2778.
- whence it arises, *ibid.* *n.* 2779, and fol.
- from one Medium into another may be determined, *p.* 140, *n.* 2856, and fol.
- when the Mediums are separated by a plane Surface, *p.* 143, *n.* 2867, and fol.
- and when separated by a spherical Surface, *p.* 151, *n.* 2915, and fol.

Refraction,

I N D E X.

- Refraction* differs according to the different Densities of the Mediums, *p.* 131, *n.* 2803.
- of diverging Rays, falling obliquely upon a more refracting Medium, determined, *p.* 145, *n.* 2882, and fol.
- Refraction*, Angle of. See *Angle*.
- Laws of demonstrated, *p.* 133, *n.* 2815, and fol.
- whence deduced, *p.* 131, *n.* 2804.
- different Cases of, *p.* 152, *n.* 2927, *p.* 153, *n.* 2934, *p.* 155, *n.* 2945, *p.* 156, *n.* 2956, *p.* 157, *n.* 2967.
- Refrangibility* different in different Rays, *p.* 239, *n.* 3465, *p.* 240, *n.* 3472, and fol.
- of Rays has a different Colour, *p.* 245, *n.* 3495.
- in all Rays is unchangeable, *p.* 247, *n.* 3513, and fol.
- is inherent in Rays, *p.* 248, *n.* 3514.
- the greater it is, the more easily Rays are reflected, *p.* 254, *n.* 3551.
- Relaxations* of a Spring. See *Spring*.
- of the Parts bent in elastick Solids, in what Time made, I, *p.* 334, *n.* 1374.
- Repulsion* of the Rays of Light, II, *p.* 116, *n.* 2726.
- Instances of it, I, *p.* 20, *n.* 87, and fol.
- the Cause of it unknown to us, II, *p.* 121, *n.* 2753.
- Resistance* and *Action* differ relatively. See *Action*.
- of a Body when it is accelerated, I, *p.* 177, *n.* 751.
- of a Cylinder moved in a Fluid, to that of a Cone, *p.* 443, *n.* 1918, *p.* 451, *n.* 1949, and fol.
- of a Globe, *p.* 444, *n.* 1919, *p.* 451, *n.* 1950.
- of a Globe moved in a Fluid to the Resistance of a Cone, *p.* 444, *n.* 1920.
- from the first Cause in different Fluids differs, *p.* 447, *n.* 1932.
- is less in swifter Motions, *ibid.* *n.* 1933.
- which a Body moved in a Fluid suffers, is not changed with the Figure of the Body, *p.* 443, *n.* 1916.
- from the second Cause is as the Density of the Fluid, *p.* 447, *n.* 1934.
- which a Body moved in a Fluid suffers, varies according to the different Figure of the Body, *p.* 143, *n.* 1917.
- instantaneous of a Body moved in a Fluid, II, *p.* 473, *n.* 2066, and fol.
- of a right Prism, moved in a Fluid, what Weight it is equal to I, *p.* 448, *n.* 1937, *p.* 449, *n.* 1943,
- which Bodies moved in Fluids suffer, whence it arises, *p.* 436, *n.* 1885, and fol.
- Resistances*, which Bodies suffer, that are moved in Fluids with different Velocities, examined by Experiments. *p.* 441, *n.* 1908, and fol.
- Rest* and *Motion* differ relatively. See *Motion*.
- of Bodies demonstrates the Equality of Motion, I, *p.* 81, *n.* 367.
- of Bodies in Collision, when it happens, *p.* 224, *n.* 962, and fol, *p.* 225, *n.* 968, and fol. *p.* 244, *n.* 1058.
- Retardation* of a Body in a Fluid, from a double Cause, *p.* 452, *n.* 1953, *p.* 455, *n.* 1975, *p.* 461, *n.* 2002, and fol, *p.* 465, *n.* 2027, and fol.
- of a Body specifically heavier than a Fluid, that ascends, or specifically lighter, that descends, *p.* 455, *n.* 1976, *p.* 468, *n.* 2040, and fol.
- in which it is projected upwards, *p.* 468, *n.* 2040, and fol.
- of a Body in a Fluid, in infinitely small Moments, is equable, *p.* 461, *n.* 2003, *p.* 471, *n.* 2059.
- of a Body in a Fluid at rest, is equal to the Velocity which it acquires, whilst the Fluid is moved, *p.* 452, *n.* 1955.
- arising from the Cohesion of Parts, *p.* 453, *n.* 1960, and fol. *p.* 462, *n.* 2008, and fol. *p.* 472, *n.* 2604, and fol.
- from the second Cause, *p.* 454, *n.* 1964, and fol. *p.* 463, *n.* 2012, and fol.
- of a Fluid. See *Fluid*.
- Retardations* of Pendulums in Fluids; *p.* 458, *n.* 1989, *p.* 459, *n.* 1991.
- Retina*, II, *p.* 174, *n.* 3068.
- Ring* of Saturn, II, *p.* 282, *n.* 3732.
- Appearances of it, *p.* 295, *n.* 3827.
- Rising* of the Stars, II, *p.* 304, *n.* 3910.
- River*, I, *p.* 399, *n.* 1667.
- in a permanent State, *p.* 399, *n.* 1668.
- regular, *p.* 405, *n.* 1707.
- bending its Course, is not always irregular, *p.* 405, *n.* 1713.
- how made, *p.* 402, *n.* 1684.
- Thread of, *p.* 405, *n.* 1708.
- Bottom of, how raised, *p.* 407, *n.* 1724, and fol.
- Mouths of, how multiplied, *p.* 407, *n.* 1724, and fol.
- Section of, *p.* 399, *n.* 1699.
- Velocity of, altered by what Causes, *p.* 403, *n.* 1689, and fol. *p.* 405, *n.* 1712, and fol. *p.* 407, *n.* 1726, and fol.
- Rivers*

I N D E X.

Rivers undergo many Alterations, *p.* 404, *n.* 1702, and fol. *p.* 406, *n.* 1715, and fol.

— all the Channels of, not made hollow by Nature, *p.* 402, *n.* 1686, *p.* 404, *n.* 1701, and fol. *p.* 407, *n.* 1723.

— Course of to be examined, *p.* 399, *n.* 1671, and fol.

— Changes of, how hindered, *p.* 408, *n.* 1733.

— Banks of, why they don't reflect the Waves, *p.* 410, *n.* 1743.

Rockets, an Explanation of their Motion, II, *p.* 70, *n.* 2447.

Romer endeavoured to determine the Velocity of Light, *p.* 99, *n.* 2621.

Ropes, Parallelism of them in Sheaves joined, may be neglected, I, *p.* 53, *n.* 267.

S.

Sagitta of a Chord, I, *p.* 315, *n.* 1283.

— encrease of it, how determined, *p.* 320, *n.* 1304, *p.* 321, *n.* 1311, and fol.

Sagitta sometimes are not varied, though the Weights be changed, *p.* 316, *n.* 1288.

— are sometimes as the bending Forces, *ibid.* *n.* 1289.

— they are sometimes as the Lengths of the Chords, *ibid.* *n.* 1291.

— which different Weights hung on the elastick Plate have given, *p.* 325, *n.* 1326, and fol.

Sand continually worn away by the flowing Water, I, *p.* 404, *n.* 1703, and fol. *p.* 405, 171, *n.* and fol.

Satellites. See *Planets Secondary*.

Saturn, II, *p.* 282, *n.* 3732.

— always appears round, *p.* 294, *n.* 3820.

— gravitates towards Jupiter and his *Satellites*, *p.* 321, *n.* 4062, and fol. 344, *n.* 4194.

— his Ring. See *Ring*.

— Motion and Distance of his *Satellites*, *p.* 283, *n.* 3745.

— Distance and periodick Time of his fourth *Satellite*, *p.* 338, *n.* 4160.

Sclerotica, II, *p.* 173, *n.* 3063.

Screw exterior, I, *p.* 58, *n.* 282.

— interior, *p.* 58, *n.* 281.

— perpetual, *p.* 63, *n.* 304.

Seasons annual, II, *p.* 313, *n.* 4008.

— in the northern Regions, *p.* 313, *n.* 4009.

— in the Southern, *p.* 314, *n.* 4010.

— in the Torrid Zone, *ibid.* *n.* 4011, and fol.

— Diversity of them, the Cause of, *p.* 312, *n.* 4002, and fol.

Section of a River. See *River*.

Segments of Spheres equally elastick, pressed inwards, I, *p.* 336, *n.* 1388, and fol.

— Comparison of the Segments of a Sphere, *p.* 205, *n.* 863, and fol.

Sensation in Physicks how to be explained, II, *p.* 48, *n.* 2311, and fol.

Senses teach nothing of themselves, II, *p.* 176, *n.* 3080.

— how we distinguish by them, *p.* 176, *n.* 3084.

Sesquiditore, II, *p.* 55, *n.* 2366.

Setting of the Stars, II, *p.* 304, *n.* 3911.

Sight, II, *p.* 175, *n.* 3076, *p.* 176, *n.* 3086.

Signs of the Zodiac. See *Zodiac*.

Sines of the Angles of Incidence and Refractions. See *Angles*.

Silver, Density of it. See *Density*.

— Weight of, I, *p.* 13, *n.* 63.

— an Ounce of, how far it may be extended, *ibid.*

Siphon, II, *p.* 38, *n.* 2258, and fol.

— for raising Water, *p.* 39, *n.* 2261.

Smoke may be turned into Flame, II, *p.* 87, *n.* 2552, and fol.

Snow mixed with Sea-salt turns Water into Ice, II, *p.* 96, *n.* 2606, and fol.

Solidity of Matter, what, I, *p.* 3, *n.* 15.

— can't be deduced from the Nature of Extension, *p.* 6, *n.* 29, and fol.

— Idea of it, how acquired, *p.* 5, *n.* 23.

— not contained in the Idea of Extension, *p.* 5, *n.* 25, and fol.

Solid specifically heavier than a Fluid in which it is suspended, does not load it more, than an equal Quantity of the same Fluid, *p.* 258, *n.* 1501, and fol.

— in which it is immersed, descends, *p.* 359, *n.* 1475.

— lighter than the Fluid in which it is immersed, ascends, *p.* 354, *n.* 1476.

— of the same specifick Gravity with the Fluid in which it is immersed, will remain suspended at any Height in the Fluid, *p.* 355, *n.* 1477.

Solids elastick examined, *p.* 333, *n.* 1372, and fol.

— immersed, what Weight they lose. See *Weight*.

— hydrostatical Comparison of them, *p.* 371, *n.* 1558, and fol.

Solstitial Points, II, *p.* 176, *n.* 3083.

Sound is heard at a different Distance, according to the Direction of the Wind, II, *p.* 53, *n.* 2345.

Sound

I N D E X.

- Sound* is encreased in a Tube by Reflection, *p.* 57, *n.* 2380, and fol.
- ceases, the tremulous Motion subsisting, *p.* 49, *n.* 2318.
- continues after the Percussion of a Body, *ibid.* *n.* 2317.
- no Sound in Vacuo, *p.* 50, *n.* 2322, and fol.
- arises from the tremulous Motion of Bodies, *p.* 49, *n.* 2313, and fol. *p.* 50, *n.* 2327.
- is propagated through Fluids, *p.* 51, *n.* 2331, and fol.
- how produced in the Ear, *p.* 51, *n.* 2334.
- is produced by the Motion of Waves in the Air. *p.* 48, *n.* 2309. *p.* 50, *n.* 2326.
- varies according to the Number of Vibrations of the Body that produces the Sound, *p.* 55, *n.* 2356.
- Intensity of it, upon what it depends, *p.* 53, *n.* 2346.
- what to be considered, to determine the Intensity of it, *p.* 53, *n.* 2348.
- in what Ratio the Intensity is, *p.* 53, *n.* 2347, *p.* 62, *n.* 2388, and fol.
- how the Intensity is changed, *p.* 54, *n.* 2349.
- the Intensity of it is encreased in compressed Air, *p.* 54, *n.* 2350, and fol.
- and is greater in Summer than in Winter, *p.* 54, *n.* 2353, and fol.
- watery Vapours obstruct the Intensity of it, *p.* 55, *n.* 2355.
- Repetition of it, whence it arises, *p.* 57, *n.* 2378.
- Repetition of the same often happens several Times, *ibid.* *n.* 2379.
- Translation of, from the tremulous Motion of Fibres, *p.* 50, *n.* 2328, and fol.
- Velocity of, *p.* 52, *n.* 2336, and fol.
- the Velocity of it differs from different Causes, *p.* 52, *n.* 2340, and fol.
- Space* is infinite, I, *p.* 5, *n.* 27.
- immoveable, *ibid.* *n.* 28.
- the Idea of it is very simple, *p.* 5, *n.* 28.
- run through, how encreased, *p.* 27, *n.* 120.
- run through, in what Ratio, *ibid.* *n.* 121.
- if the Space run through it is the same, the Action is the same, *p.* 171, *n.* 728, *p.* 199, *n.* 837.
- Space* taken up by Matter that becomes elastick, is very small, whilst inherent in Bodies, II, *p.* 11, *n.* 2126.
- Spaces* run through by a falling Body, I, *p.* 83, *n.* 374, and fol.
- and by a Body running along a plane, *p.* 84, *n.* 384, and fol.
- and by Bodies moved through a Fluid, *p.* 455, *n.* 1973, and fol.
- run through by central Forces, *p.* 151, *n.* 645, and fol.
- Sphere* oblique, II, *p.* 307, *n.* 3946.
- parallel, *ibid.* *n.* 3945.
- right, *p.* 308, *n.* 3960.
- Sphere* of the fixed Stars, *p.* 287, *n.* 3773.
- Comparison of the Segments of a Sphere. See *Segments*.
- Spheres* elastick how pressed inwards, I, *p.* 334, *n.* 1375, and fol.
- Spherical* Surface, how considered 2, *p.* 151, *n.* 2917.
- Spiral* Logarithmic, I, *p.* 9, *n.* 47, and fol.
- how to be measured, *p.* 10, *n.* 51, and fol.
- one may differ from another in Length, *ibid.* *n.* 54.
- Spirit* of Turpentine, Density of it to that of Water. See *Water*.
- Spots* white in the Heavens, II, *p.* 318, *n.* 4044.
- made by elastick Spheres, of what Kind, I, *p.* 335, *n.* 1384, and fol. *p.* 337, *n.* 1393, and fol.
- Spring*, how it appears that it is relaxed in equal Times, I, *p.* 184, *n.* 784, and fol.
- moved with a Ship, what Force it communicates, *p.* 270, *n.* 1145.
- whilst it is relaxed, what Action it produces, *p.* 328, *n.* 1343, and fol.
- bent what Forces it communicates to Bodies moved by it, *p.* 254, *n.* 1087. *p.* 257, *n.* 1095, and fol.
- bent between suspended Bodies how relaxed, *p.* 255, *n.* 1090, and fol.
- what Velocities it communicates to them. See *Velocities*.
- the same, whether relaxed slower or faster, communicates equal Force to a Body, *p.* 172, *n.* 731, *p.* 176, *n.* 745.
- what Force it exerts, at that Part, at which it is moved, *p.* 268, *n.* 1140, and fol.
- if Bodies are moved opposite Ways after the Stroke, *p.* 269, *n.* 1144.
- whereby a Pendulum is moved, *p.* 174, *n.* 739.
- Action* of, in elastick Bodies is very sudden, *p.* 264, *n.* 1127, and fol.
- wrongly estimated by some, *p.* 184, *n.* 783.
- Defect
H h h

I N D E X.

- Spring*, Defect of its Elasticity, how determined, *p.* 329, *n.* 1349.
- Relaxations of, communicated Forces which are as the Squares of the Inflections, *p.* 328, *n.* 1344.
- what Velocities they communicate, *p.* 328, *n.* 1345.
- Squares* of natural Numbers, their Sum, I, *p.* 120, *n.* 534.
- Stars* fixed, II, *p.* 103, *n.* 2640, *p.* 278, *n.* 3688, *p.* 315, *n.* 4023, and fol.
- describe Ellipses, *p.* 105, *n.* 2648, and fol.
- seen with a Telescope, appear like a lucid Point, *p.* 316, *n.* 4027.
- do not all appear equally lucid, *p.* 317, *n.* 4036, and fol.
- some are periodical, *ibid.* *n.* 4042.
- some have appeared, and quite vanished, *ibid.* *n.* 4043.
- a great Number of them discovered by Telescopes, *ibid.* *n.* 4041.
- Steelyard* Compound, I, *p.* 61, *n.* 294, and fol.
- Roman, *p.* 38, *n.* 193, and fol.
- Stones* calcined, several shine, after they have been exposed to the Sun, II, *p.* 66, *n.* 2422.
- Stroke* oblique, I, *p.* 216, *n.* 922.
- depends upon the respective Velocity, *p.* 221, *n.* 948.
- Subtily* of Parts, I, *p.* 13, *n.* 63.
- Subtraction* Mechanical, I, *p.* 44, *n.* 228.
- Support* for two Prisms, II, *p.* 252, *n.* 3539, and fol.
- System* Planetary, II, *p.* 278, *n.* 3686.
- consists of seventeen spherical Bodies, *p.* 278, *n.* 3690.
- is the Object of Astronomy, *ibid.* *n.* 3687.
- Physical Explanation of the planetary System, *p.* 341, *n.* 4108, and fol.
- Dimensions of it, *p.* 281, *n.* 3725, and fol.
- Syzygies*, II, *p.* 296, *n.* 3840.
- T.
- Table* Horizontal, II, *p.* 126, *n.* 2773.
- Tables*, whose Height is altered, II, *p.* 126, *n.* 2774.
- through which Light is transmitted, *p.* 125, *n.* 2768, and fol.
- Table* exhibiting the Powers and Actions in the Lever, I, *p.* 111, *n.* 496.
- how it was made, *p.* 116, *n.* 520.
- of Indices and Powers in Machines, *p.* 114, *n.* 508.
- how it is constructed, *p.* 120, *n.* 536, and fol.
- of Use in the Computations concerning the Quantity of Water running out of a given Hole, *p.* 391, *n.* 1637, *p.* 398, *n.* 1664, and fol.
- for comparing together the Segments of a Sphere and Cone, *p.* 206, *n.* 867.
- Tables* of the Resistances, that Bodies, moved in Fluids with different Velocities, suffer, *p.* 441, *n.* 1908, *p.* 442, *n.* 1911, *p.* 443, *n.* 1914, *p.* 444, *n.* 1922, and fol. *p.* 446, *n.* 1929, and fol. *p.* 450, *n.* 1945.
- of the Dimensions of a Cycloid, *p.* 101, *n.* 462, *p.* 101, *n.* 464, and fol.
- Tackle*, I, *p.* 53, *n.* 263.
- Telescope*, II, *p.* 192, *n.* 3193.
- astronomical, *p.* 192, *n.* 3194, and fol.
- in what different from the Microscope, *p.* 193, *n.* 3197.
- for viewing terrestrial Objects, *p.* 193, *n.* 3199, and fol.
- how much it magnifies Objects, determined, *p.* 195, *n.* 3207.
- through which an Object appears erect, *ibid.* *n.* 3209, and fol.
- Length of, *p.* 196, *n.* 3215.
- Perfection of, *ibid.* *n.* 3216.
- Telescopes*, why less perfect, *p.* 254, *n.* 3550.
- catoptric, their Length, *p.* 220, *n.* 3357, *p.* 225, *n.* 3390, and fol.
- their Aperture, *p.* 220, *n.* 3357, and fol.
- how much they magnify, *p.* 220, *n.* 3354, *p.* 220, *n.* 3358, *p.* 222, *n.* 3369, and fol. *p.* 224, *n.* 3388, *p.* 228, *n.* 3406, and fol.
- Telescopes* catoptric, how they represent Objects, *p.* 221, *n.* 3360.
- Gregorian, *p.* 221, *n.* 3364, and fol.
- what Aperture they should have, 223, *n.* 3378.
- compared together, *p.* 228, *n.* 3410, and fol.
- and with Dioptric ones, *p.* 230, *n.* 3420, and fol.
- Newtonian, *p.* 219, *n.* 3350, and fol.
- brought to Perfection by Hadley, *p.* 221, *n.* 3361.
- compared together, *p.* 227, *n.* 3402, and fol.
- and with the Gregorian ones, *p.* 224, *n.* 3385, *p.* 230, *n.* 3417.
- Apertures and Eye-glasses of Telescopes determined, *p.* 198, *n.* 3229, and fol.
- Things* natural, I, *p.* 1, *n.* 1.
- Thread*

I N D E X.

- Thread* of a River. See *River*.
- Thermometer*, whether it shews the Degree of Heat, II, *p.* 67, *n.* 2432.
- if it is made hot suddenly, the Fluid in the Tube descends, *p.* 68, *n.* 2433, and fol.
- Thermometers* are affected in the same Manner by neighbouring Bodies, *p.* 82, *n.* 2506, and fol. *p.* 83, *n.* 2154.
- Tide*, II, *p.* 381, *n.* 4463, and fol.
- is derived from the Action of the Sun and Moon, *p.* 380, *n.* 4457, and fol. *p.* 381, *n.* 4469, and fol.
- none under the Pole, *p.* 381, *n.* 4467.
- not always the same, *p.* 382, *n.* 4473, and fol.
- near *Bristol*, *p.* 384, *n.* 4491.
- the Forces of the Sun and Moon for producing it determined, *p.* 384, *n.* 4485, and fol.
- how the Surface of the Sea, in Tides, constitutes itself, *p.* 366, *n.* 4324.
- Time* of the Action of a Cylinder on Clay, the Ratios of, I, *p.* 205, *n.* 859, and fol. *p.* 210, *n.* 884, and fol.
- of the rolling of a Body along an inclined Plane, *p.* 85, *n.* 388, and fol.
- absolute or true, *p.* 26, *n.* 117.
- relative, *p.* 26, *n.* 118.
- mean, II, *p.* 310, *n.* 3973.
- Periodic. See *Periodic*.
- in which a Spring is bent, I, *p.* 329, *n.* 1351, and fol.
- which is of Use in the Experiment relating to Velocities communicated, *p.* 329, 1351, *n.* and fol. *p.* 332, *n.* 1365, and fol.
- of a Vibration, its Ratio to the Time of a vertical Fall, *p.* 91, *n.* 415, *p.* 103, *n.* 470.
- Equation of, II, *p.* 310, *n.* 3973.
- Consideration of, may be neglected, in determining the Effect, that a Body produces, whilst it loses Force, I, *p.* 171, *n.* 728, *p.* 196, *n.* 826, *p.* 199, *n.* 836, and fol.
- Times* in which Cavities are made, how determined, *p.* 208, *n.* 868, and fol. *p.* 209, *n.* 881, and fol.
- these Times are compared, *p.* 212, *n.* 899, and fol.
- in which a Fluid runs out through Holes, of what Kind, *p.* 392, *n.* 1641, and fol.
- in which the Inflections of elastick Bodies are made, of what Kind, *p.* 337, *n.* 1397, and fol.
- in which Percussions are made, how compared together, *p.* 237, *n.* 1025, and fol.
- in which a Lever raises a Weight by Means of different Powers, how compared, *p.* 116, *n.* 519.
- the Squares of the Times of the Actions of some Bodies against Clay, are as the Masses, *p.* 205, *n.* 862, *p.* 211, *n.* 891, and fol.
- Tone* does not depend upon the Intensity of Sound, II, *p.* 55, *n.* 2359.
- Musical, on what it depends, *ibid.* *n.* 2357.
- degrees of Sharpness of different ones, their Ratio to one another, *ibid.* *n.* 2358.
- Toricellian* Tube, II, *p.* 3, *n.* 2086.
- Translation*, what, I, *p.* 28, *n.* 128.
- Tropics*, II, *p.* 302, *n.* 3894, and fol.
- Tubes* for speaking Trumpets, their most perfect Figure, *p.* 57, *n.* 2380.
- Twilight*, II, *p.* 310, *n.* 3977.
- Cause of *Twilights*, *ibid.* *n.* 3977.
- Cause of *Twilights*, *ibid.* *n.* 3978.

V.

- Vacuum*, I, *p.* 4, *n.* 21.
- is possible, *ibid.* *n.* 22.
- proved, II, *p.* 330, *n.* 4120, and fol.
- Vapour* takes up much less Space than Water, II, *p.* 11, *n.* 2127, *p.* 12, *n.* 2133, and fol.
- why equally hot with boiling Water, *p.* 83, *n.* 2513.
- elastick Force of, *p.* 69, *n.* 2441, and fol.
- Vapours* sometimes appear suddenly in the Air, *p.* 87, *n.* 2544, and fol.
- Velocity*, I, *p.* 26, *n.* 119.
- acquired, *p.* 82, *n.* 372.
- of the Water of a River. See *Water*.
- is encreased as long as a Body is pressed, *p.* 167, *n.* 697.
- of a Body projected upwards, *p.* 83, *n.* 377, and fol.
- and in any Point, *p.* 127, *n.* 556.
- of Bodies descending on an inclined Plane, *p.* 84, *n.* 384, and fol.
- of Bodies descending in a Curve, *p.* 86, *n.* 393.
- is communicated to Fluids by Pressure, *p.* 376, *n.* 1575, and fol.
- whereby a Fluid spouts, by the Pressure of a superincumbent Fluid, of what Kind, *p.* 378, *n.* 1583, *p.* 379, *n.* 1585.
- of a River. See *River*.
- Velocity

I N D E X.

- Velocity* an equal, lateral is not always communicated by an equal Impression, *p.* 272, *n.* 1150.
- of Light. See *Light*.
- greatest of an accelerated Body, *p.* 456, *n.* 1978, and fol, *p.* 470, *n.* 2053, and fol.
- of a Pendulum. See *Pendulum*.
- after a Stroke, common to Bodies, tending towards the same Part, how had, *p.* 229, *n.* 988, and fol. *p.* 234, *n.* 1011.
- after a Stroke, common to Bodies, tending towards contrary Parts, how had, *p.* 229, *n.* 990, and fol, *p.* 235, *n.* 1012, and fol.
- after the Stroke, in the Collision of three non-elastic Bodies, *p.* 285, *n.* 1184, *p.* 294, 1214.
- if a Body runs directly against another, which coheres with other Bodies, how had, *p.* 246, *n.* 1069.
- of a Point, in which is made the Percussion of different Bodies joined, how had, *p.* 241, *n.* 1045, *p.* 245, *n.* 1064.
- respective, *p.* 216, *n.* 917, and fol.
- double, what respective Action it gives, *p.* 231, *n.* 1001.
- of Sound. See *Sound*.
- equal Degrees of, how communicated, *p.* 168, *n.* 705.
- Change of in the striking of elastic Bodies, with respect to all, of what Kind, *p.* 286, *n.* 1188, and fol.
- Velocities* acquired and lost often denote the same Change, *p.* 166, *n.* 689, and fol.
- communicated by a Spring bent, *p.* 254, *n.* 1088, and fol. *p.* 257, *n.* 1096, and fol.
- and by a Spring relaxed, of what Kind, *p.* 328, *n.* 1345, and fol. *p.* 331, *n.* 1360, and fol.
- of a Body that is retained in a Curve by a central Force, *p.* 151, *n.* 643.
- of falling Bodies compared, *p.* 89, *n.* 403.
- of elastic Bodies, after the Stroke, their Laws, *p.* 260, *n.* 1110, and fol.
- Velocities* of Bodies in the Motion of a Pendulum, *p.* 106, *n.* 478.
- after the Stroke how determined, *p.* 228, *n.* 987, and fol. *p.* 245, *n.* 1064, and fol.
- which communicate Motion by Pressure alone, *p.* 307, *n.* 1256.
- of Pendulums in a Fluid, of what Sort, *p.* 457, *n.* 1987.
- with which a Fluid runs out of different Holes, of what Kind, *p.* 397, *n.* 1586, and fol.
- Decrements of, in Collision, *p.* 225, *n.* 967.
- Changes of the Velocities of two Bodies, arising from their mutual Action in Collision, of what Kind, *p.* 285, *n.* 1186, *p.* 294, *n.* 1216.
- Changes of, in Collision, which happen in certain Times, examined, *p.* 237, *n.* 1026, and fol.
- in double Collision, when made in equal Time, *p.* 291, *n.* 1205, *p.* 293, *n.* 1212.
- Changes of, made by oblique Percussion, *p.* 279, *n.* 1172, and fol.
- Ratio of, when in Percussion various Bodies joined are at Rest, *p.* 244, *n.* 1057, and fol.
- Venus*, II, *p.* 281, *n.* 3728.
- Distance of from the Sun and periodical Time, *p.* 338, *n.* 4158.
- Vibrations* of a Plate, one of whose Ends is fixed, *p.* 325, *n.* 1333, and fol.
- though unequal, are of the same Continuance, *p.* 316, *n.* 1292.
- greater of a Pendulum in a Fluid, are of longer Continuance, *p.* 457, *n.* 1986.
- Vibrations* all of the same Plate are of the same Continuance, *p.* 326, *n.* 1335.
- of equal Pendulums in a Fluid, are of the same Continuance, *p.* 456, *n.* 1983.
- Times of the Vibrations of Chords, *p.* 317, *n.* 1293, and fol.
- Visible* Point, where it appears, II, *p.* 182, *n.* 3121, and fol.
- Vision* confused, II, *p.* 177, *n.* 3088.
- distinct, *p.* 177, *n.* 3087.
- has diverse Limits, *p.* 178, *n.* 3098, and fol.
- is distinct for one Point, only at the same Time, *p.* 179, *n.* 3107, and fol.
- through a Lense how it differs from Vision with the naked Eye, *p.* 185, *n.* 3145.
- through a concave Lense, *p.* 185, *n.* 3140, and fol.
- through a convex Lense, *p.* 184, *n.* 3131, and fol.
- Vision* through a polyhedrous Lense, *p.* 187, *n.* 3156.
- through a plane Glass, *p.* 183, *n.* 3126, and fol.
- Limit of Vision in the same Man is sometimes near and sometimes remote, so that

I N D E X.

- that intermediate Objects appear confused, *p.* 178, *n.* 3100.
- by Vision through Water Objects appear magnified, *p.* 184, *n.* 3130.
- how we judge of Distance, by Vision, *p.* 180, *n.* 3109, and fol.
- and through Glasses, *p.* 182, *n.* 3124, and fol.
- and by Magnitude, *p.* 181, *n.* 3118.
- Vitreous Humour.* See *Humour.*
- Unison* II, *p.* 55, *n.* 2361.
- Universe*, what, I, *p.* 1, *n.* 1.
- governed by determinate Laws, *p.* 2, *n.* 4.
- Urine*, Phosphorus of. See *Phosphorus.*
- Use* of Machines. See *Machines.*
- Uvea*, II, *p.* 173, *n.* 3064.
- W.
- Water* acts two Ways upon Hydraulic Machines, *p.* 428, *n.* 1848, and fol.
- ascends through a Pump, II, *p.* 10, *n.* 2199, and fol. *p.* 30, *n.* 2266.
- but not in Vacuo, *p.* 25, *n.* 2200, and fol.
- ascends through a Syphon, *p.* 39, *n.* 2264, and fol.
- why it runs out of a Syphon, *p.* 38, *n.* 2259, and fol.
- is attracted by Glass, *p.* 22, *n.* 99, and fol.
- is melted Ice, *p.* 68, *n.* 2439.
- puts out Fire, *p.* 95, *n.* 2593, and fol.
- does not extinguish some Fluids that are set on Fire, *p.* 95, *n.* 2596.
- in a River, the lower moves faster than the upper, I. *p.* 401, *n.* 1678, and fol.
- moved through an Horizontal Channel, and how, *p.* 403, *n.* 1696, and fol.
- Water* in a River moves slower, where it is remote from the Head, *p.* 403, *n.* 1692.
- when accelerated, *p.* 403, *n.* 1694.
- when it is carried with an equable Motion, *p.* 403, *n.* 1691.
- carries Sand along with it, *p.* 404, *n.* 1703, and fol. *p.* 405, *n.* 1710, and fol.
- when it comes to the Bank with a certain Impetus, what Effect it produces. *p.* 406, *n.* 1717.
- by what Action sustained in a Tube, *p.* 423, *n.* 1813, and fol.
- with what Action cast upwards, *p.* 424, *n.* 1817, and fol.
- repels fat Bodies, *p.* 20, *n.* 87.
- retains the Fire contained in the Phosphorus of Urine, II, *p.* 81, *n.* 2499.
- Adhesion of it to Glass and Wood, I, *p.* 19, *n.* 86.
- Height of it, the farther you go from the Head of a River, continually diminishes, *p.* 400, *n.* 1673.
- Ascent of between two Glass Planes, *p.* 19, *n.* 84, *p.* 19, *n.* 85, *p.* 23, *n.* 106, and fol.
- Ascent of it in Glass Tubes, *p.* 18, *n.* 82, and fol. *p.* 23, *n.* 104, and fol. *p.* 24, *n.* 107.
- Column of, sustained by Air, II. *p.* 3, *n.* 2089.
- Density of, to that of the Spirit of Turpentine, *p.* 39, *n.* 2851.
- the same Quantity flows out in the same Time through Sections of a River in a permanent State, I, *p.* 399, *n.* 1670.
- the Velocity of the lower and upper Water, in the Progress of a River, continually approaches towards an Equality, *p.* 401, *n.* 1679.
- Height of in a River, when obstructed by a Cataract, *p.* 401, *n.* 1681.
- Velocity of in a River is not altered, as the Quantity of Water encreases, *p.* 401, *n.* 1680.
- Velocity of in different Parts of a River, how determined, *p.* 400, *n.* 1674, and fol.
- Weight of, *p.* 13, *n.* 63.
- Velocity of in a Tube how determined, *p.* 420, *n.* 1674, and fol.
- Watery Parts* in Bodies, II, *p.* 87, *n.* 2549.
- Wave* I, *p.* 409, *n.* 1738.
- how made, *p.* 409, *n.* 1737, *p.* 411, *n.* 1747.
- of Air. See *Air.*
- Breadth of one, *p.* 409, *n.* 1739.
- Motion of, of what Sort, *p.* 409, *n.* 1740.
- Motion of one behind an Obstacle, *p.* 410, *n.* 1744, and fol.
- Reflection of, how made, *p.* 409, *n.* 1741, and fol.
- various Waves don't disturb one another, *p.* 411, *n.* 1748.
- Celerity of them how determined, *p.* 411, *n.* 1749, *p.* 413, *n.* 1753, and fol.
- Way* milky, II, *p.* 317, *n.* 4038, and fol.
- run through by a spouting Fluid, by what Experiments determined, I, *p.* 386, *n.* 1615, and fol.
- Wedge*, I, *p.* 55, *n.* 272.

Wedge

I N D E X.

Wedge, Edge of it, *p.* 55, *n.* 275.

—— Height of, *p.* 55, *n.* 273.

—— Base of, *p.* 55, *n.* 274.

Weighing, most exact Method of, *I.* *p.* 366, *n.* 1536, and fol.

Weight, lost by a Solid immersed in Fluids of a different Density, *I.* *p.* 358, *n.* 1498, and fol.

—— of a Body, *p.* 31, *n.* 149.

—— considered as a Power, *p.* 32, *n.* 151, *p.* 33, *n.* 157.

—— how it gravitates upon the Point of Suspension, *p.* 37, *n.* 183.

—— which is sustained by Powers drawing obliquely, *p.* 71, *n.* 332, and fol. *p.* 72, *n.* 336, and fol.

—— Action of one for moving a Balance, *p.* 37, *n.* 185, and fol.

Weights lost by a Body, immersed in different Fluids, are as the Densities of the Fluids, *p.* 368, *n.* 1545.

—— lost by equal Solids, immersed in a Fluid, are equal, *p.* 317, *n.* 1493, and fol.

—— lost by unequal Solids immersed in a Fluid, are in the Ratio of the Bulks, *p.* 358, *n.* 1495.

—— lost of the same Weight, but of different Density immersed in the same Fluid, of what Kind, *p.* 358, *n.* 1496, and fol.

—— are explored by a Balance, *p.* 36, *n.* 179.

—— how exactly determined, *p.* 363, *n.* 1520, and fol.

—— which are sustained by one Power only, *p.* 48, *n.* 245.

—— applied to a Lever, have a common Center of Gravity, *p.* 48, *n.* 246.

—— considered with respect to their Bulks and Densities, *p.* 353, *n.* 1465.

—— are as the Quantities of Matter, *p.* 33, *n.* 156.

Western Part, *II.* *p.* 304, *n.* 3916.

West, Point of, *II.* *p.* 335, *n.* 3919.

Wheels moved by the Force of Water, their Actions, *I.* *p.* 430, *n.* 1864.

Wind, Action of upon the Sails of an Hydraulic Machine, difficult to be determined, *I.* *p.* 428, *n.* 1846.

—— Velocity of is less than the Velocity of Sound, *II.* *p.* 53, *n.* 2342.

Wood, cleaving of, *I.* *p.* 59, *n.* 286.

—— lucid soon loses it's Light in Vacuo, *II.* *p.* 85, *n.* 2529.

World, Poles of. See *Poles*.

Y.

Year great, *II.* *p.* 314, *n.* 4018.

—— periodical, exceeds the tropical Year, *p.* 281, *n.* 3729.

Z.

Zenith, *II.* *p.* 304, *n.* 3912.

Zodiac, *II.* 289, *n.* 3791.

—— Signs of, *p.* 288, *n.* 3783, *p.* 316, *n.* 4029.

Zone Torrid, Phænomena of, *II.* *p.* 311, *n.* 3991, *p.* 312, *n.* 3995, and fol.

Zones, *p.* 311. *n.* 3987, and fol.

—— Phænomena of the Temperate, *p.* 306, *n.* 3933, and fol.

—— Phænomena of the Frigid, *p.* 312. *n.* 3993, *ibid.* *n.* 3998, and fol.

E R R A T A.

Page 4 Line 3, from the Bottom, for *with* read *to*.

Page 99 and following, for *Reaumur* read *Romer*.

